

Papers Presented to the

**CONFERENCE ON LARGE BODY IMPACTS
AND TERRESTRIAL EVOLUTION: GEOLOGICAL,
CLIMATOLOGICAL, AND BIOLOGICAL IMPLICATIONS**

(NASA-CR-164880) PAPERS PRESENTED TO THE
CONFERENCE ON LARGE BODY IMPACTS AND
TERRESTRIAL EVOLUTION: GEOLOGICAL,
CLIMATOLOGICAL, AND BIOLOGICAL IMPLICATIONS
(Lunar and Planetary Inst.) 89 p

N81-33520

HC A05/MF A01

Unclas

G3/42 37976

**October 19-22, 1981
Snowbird, Utah**

Sponsored by:

**Lunar and Planetary Institute
National Academy of Sciences**



UNIVERSITIES SPACE RESEARCH ASSOCIATION
LUNAR AND PLANETARY INSTITUTE
3303 NASA ROAD 1
HOUSTON, TEXAS 77058

Papers Presented to the

CONFERENCE ON LARGE BODY IMPACTS

AND TERRESTRIAL EVOLUTION: GEOLOGICAL,
CLIMATOLOGICAL, AND BIOLOGICAL IMPLICATIONS

SPONSORED BY:

LUNAR AND PLANETARY INSTITUTE
NATIONAL ACADEMY OF SCIENCES

OCTOBER 19-22, 1981

SNOWBIRD, UTAH

Compiled by the
Lunar and Planetary Institute
3303 NASA Road One
Houston, Texas 77058

LPI CONTRIBUTION 449

Compiled in 1981

by

LUNAR AND PLANETARY INSTITUTE

Material in this volume may be copied without restraint for library, abstract service, educational or personal research purposes; however, republication of any paper or portion thereof requires the written permission of the authors as well as appropriate acknowledgement of this publication.



PREFACE

This volume contains papers which have been accepted for publication by the Program Committee of the Conference on Large Body Impacts and Terrestrial Evolution: Geological, Climatological, and Biological Implications. Papers were solicited which address one of the following major topics:

1. Nature and flux of near-Earth objects and the geological evidence of their interactions
2. Physics of high energy impacts
3. The biological record and evidence for catastrophic extinction
4. Searching the extensive geological record for physical evidence of major impacts
5. Meteorological and climatological consequences of large scale impacts

The Program Committee consists of L. Silver, Chairman (California Institute of Technology); K. Burke (State University of New York at Albany); G. Carrier (Harvard University); L. Hunt (National Academy of Sciences); H. Lowenstam (California Institute of Technology); J. Murray-Mitchell (Environmental Data & Information Services); R. O. Pepin (University of Minnesota); P. Schultz (Lunar and Planetary Institute); E. Shoemaker (U.S.G.S., Flagstaff); and G. Wetherill (Carnegie Institution).

Logistic and administrative support for this conference has been provided by P. H. Jones (Projects Administrator, Lunar and Planetary Institute, Houston). This volume was compiled by K. Hrametz (Technical Editor, Lunar and Planetary Institute, Houston).

Papers are arranged alphabetically by the name of the first author. Indices by heavenly body, subject, and author are provided.

The Lunar and Planetary Institute is operated by the Universities Space Research Association under contract No. NASW-3389 with the National Aeronautics and Space Administration.

TABLE OF CONTENTS

<i>Effect of the atmosphere and ocean on the impact of the Cretaceous-Tertiary bolide</i> T. J. Ahrens and J. D. O'Keefe	1
<i>Geochemical anomalies near the Eocene-Oligocene and Permian-Triassic boundaries</i> F. Asaro, L. W. Alvarez, W. Alvarez, and H. V. Michel	2
<i>Signal events in the pre-Cambrian biosphere</i> S. M. Awramik	3
<i>Investigations of the Slate Islands Crater</i> M. E. Bengtson and R. P. Meyer	4
<i>Extinction at the end of the Cretaceous in boreal shelf seas -- A multicausal event</i> T. Birkelund	5
<i>The relationship of cooling, subsidence, and thermal stress to the topography and tectonics of multi-ringed basins</i> S. R. Bratt, S. C. Solomon, and J. W. Head	6
<i>Paleomagnetic polarity stratigraphy of the Cretaceous/Tertiary boundary, San Juan Basin, New Mexico</i> R. F. Butler, E. H. Lindsay, and N. M. Johnson	7
<i>Patterns of extinction and survival of the terrestrial biota during the Cretaceous-Tertiary transition</i> W. A. Clemens	8
<i>A first-order estimate of vaporization in oceanic impacts</i> S. K. Croft	9
<i>Search for large body impact craters on the ocean floors</i> O. Eckhoff and P. Vogt	10
<i>Evidence for (or against) a large-scale impact resulting in a catastrophic extinction at the Cretaceous-Tertiary boundary in the San Juan Basin, New Mexico and Colorado</i> J. E. Fassett	11

PRECEDING PAGE BLANK NOT FILMED

<i>Thermal effects of large impacts</i> E. S. Gaffney	12
<i>Laboratory simulation of pelagic asteroid impact</i> D. E. Gault and C. P. Sonett	13
<i>Reduction of photosynthetically active radiation under extreme stratospheric aerosol loads</i> S. A. W. Gerstl and A. Zardecki	14
<i>Possible correlation between tektite falls and other events</i> B. P. Glass	15
<i>The record of large scale impact on Earth</i> R. A. F. Grieve	16
<i>The southern Gulf of St. Lawrence as an impact structure: A preliminary investigation</i> J. B. Hartung	17
<i>Paleoclimatic significance of high iridium concentrations in Pleistocene deep-sea sediments</i> J. D. Hays	18
<i>Land plant change across the Cretaceous-Tertiary boundary</i> L. J. Hickey	19
<i>Large body impact and the pre-Cambrian: Need for multiple origins of life?</i> R. C. Hoagland	20
<i>Scaling considerations for kilometer-sized impactors</i> K. A. Holsapple	21
<i>Atmospheric effects of large-body impacts: The first few minutes</i> E. M. Jones, M. T. Sandford, II, and R. W. Whitaker	22
<i>Graded extinctions related to broad environmental deterioration in the Cretaceous</i> E. G. Kauffman	23
<i>A large-scale positive-gravity anomaly in northeastern North America: Possible evidence for large-scale meteorite impact</i> J. S. Klasner, W. F. Cannon, and K. J. Schulz	24
<i>Geochemical evidence for major accretion events</i> F. T. Kyte and J. T. Wasson	25

<i>Rochechouart: Geochemistry</i> P. Lambert	26
<i>Rochechouart: Geology</i> P. Lambert	27
<i>Comparative morphology, paleoecology and paleo- biogeography of massive extinctions and evolutionary radiations in marine plankton</i> J. H. Lipps	28
<i>More definitive strategies to assess likely ecologic effects of large body impacts on marine life</i> H. A. Lowenstam	29
<i>Tests of a proposed extraterrestrial cause for the Frasnian-Famennian (late Devonian) extinction event</i> G. R. McGhee, Jr., R. Ganapathy, and E. J. Olsen	30
<i>Verified impact structures in Brazil</i> J. F. McHone, Jr.	31
<i>Tin Bider multi-ring impact structure (Algeria)</i> J. F. McHone, P. Lambert, R. S. Dietz, and M. Houfani	32
<i>Formation of noctilucent clouds by an extraterrestrial impact</i> C. P. McKay and G. E. Thomas	33
<i>Impact into the earth's ocean floor during the last billion years: Preliminary experiments, theoretical models, and possibilities for geological detection</i> W. B. McKinnon and P. Goetz	34
<i>Frasnian-Famennian extinctions</i> D. J. McLaren	35
<i>Diachroneity of the K-T contact and of the dinosaurian extinctions</i> D. M. McLean	36
<i>The mechanics of large meteoroid impacts in the earth's ocean</i> H. J. Melosh	37
<i>Response times of pelagic marine ecosystems following a global blackout</i> D. H. Milne and C. McKay	38

<i>Impact mechanics of large bolides interacting with the earth and their implication to extinction mechanisms</i>	
J. D. O'Keefe and T. J. Ahrens	39
<i>Permo-Triassic vertebrate extinctions</i>	
E. C. Olson	40
<i>Energy coupling for meteoritic and cometary impacts</i>	
D. L. Orphal, D. J. Roddy, P. H. Schultz, W. F. Borden, and S. A. Larson	41
<i>Iridium abundance measurements across the Cretaceous-Tertiary boundary in the San Juan and Raton Basins of northern New Mexico</i>	
C. J. Orth, J. S. Gilmore, J. D. Knight, C. L. Pillmore, R. H. Tschudy, and J. E. Fassett	42
<i>The identification of projectiles of large terrestrial impact craters</i>	
H. Palme	43
<i>Cambrian extinction events</i>	
A. R. Palmer	44
<i>Precision bio- and isotope-stratigraphy and the "catastrophic" extinction of calcareous nannoplankton at the Cretaceous/Tertiary boundary</i>	
K. Perch-Nielsen, Q. He, and J. McKenzie	45
<i>Size:rank of rings for large impact craters: Systematic traces in the earth's rocks</i>	
R. J. Pike	46
<i>Biogeographic extinction: A feasibility test</i>	
D. M. Raup	47
<i>Crater size for large-body impact</i>	
R. M. Schmidt	48
<i>Extinction of the dinosaurs</i>	
T. J. M. Schopf	49
<i>Impact cratering in an atmosphere</i>	
P. H. Schultz and D. E. Gault	50
<i>Evidence of oceanic impact of large meteorites</i>	
R. J. Seymour	51

<i>Synthesis of stratigraphical, micropaleontological and geochemical evidence from the K-T boundary; Indication for cometary impact</i> J. Smit	52
<i>Hawaii as a consequence of an impact; Precipitation driven magma convection</i> H. J. Smith and R. Smoluchowski	53
<i>Extinction or survival and diversification: Patterns of selectivity during Paleozoic crises</i> H. Tappan	54
<i>Terminal Cretaceous plankton extinctions: A critical assessment</i> H. R. Thierstein	55
<i>Large body impacts: Evolution of the dust cloud and its effects on the atmosphere</i> O. B. Toon, J. B. Pollack, R. P. Turco, C. P. McKay, and M. Liu	56
<i>The Tunguska meteor: Effects on stratospheric ozone, ultraviolet radiation, and climate</i> R. P. Turco, O. B. Toon, C. Park, R. C. Whitten, and P. Noerdlinger	57
<i>An idea for the use of $^{187}\text{Os}/^{186}\text{Os}$ in high iridium layers in sedimentary strata as a clue to determining cosmic versus terrestrial origin of such layers</i> K. K. Turekian	58
<i>Effects of cometary impacts on atmospheric mass and composition</i> G. H. Watkins and J. S. Lewis	59
<i>Stratospheric injection of ocean water by pelagic asteroidal impacts</i> R. C. Weeks	60
<i>Terrestrial impact rates for long and short-period comets</i> P. R. Weissman	61
<i>The nature of large impacting projectiles</i> G. W. Wetherill	62
Heavenly Body Index	63
Subject Index	64
Author Index	68

EFFECT OF THE ATMOSPHERE AND OCEAN ON THE IMPACT OF THE
 CRETACEOUS-TERTIARY BOLIDE by Thomas J. Ahrens and John D. O'Keefe,
 Seismological Laboratory, California Institute of Technology, Pasadena,
 California 91125.

Two-dimensional finite-difference compressible hydrodynamic calculations of the flows induced by impact of water and silicate, ~ 10 km diameter, bolides on the earth's atmosphere, ocean and solid surface at speeds varying from 5 to 72 km/sec demonstrate that the direct energy transfer to the atmosphere and ocean of a possible K-T impactor, even if highly distended in the form of a swarm or stream of particles, is very small. The major mechanism for coupling energy into the atmosphere is the work done on the atmosphere by the expansion of the impact ejecta plume which is largely composed of terrestrial material excavated from a yet to be discovered marine (not subducted) or continental target site. Whereas most of the ejecta has a extraterrestrial component (ETC) of from 10^{-5} to 10^{-2} from assumed impacts at speeds which vary from 5 to 45 km/sec for silicate objects and even lower concentrations for cometary objects and is deposited locally, the extremely enriched siderophile rare element clay layer discovered by Alvarez and others has quite a unique origin. We have found that ejecta from the impact on the solid earth is launched upwards in a trajectory which is nearly normal to the earth's surface at speeds of >0.5 km/sec at a normalized time, $\sim 2\tau$, and its composition varies from nearly pure ETC to concentration of 10^{-3} ETC depending on the type of impactor. Normalized time, τ , is defined as $\tau = tv/d$ where t is real time, v is impactor velocity and d is bolide diameter. During the same time interval atmospheric impact calculations demonstrate that the bolide has effectively compressed the entire atmosphere beneath its cross section to a very thin layer (e.g. at ~ 100 kbar for 72 km/sec bolide). The compression of the atmosphere over the aerial extent of the bolide creates a hole or window to the stratosphere and exosphere through which the ETC rich ejecta can be lofted. This hole, or shutter, in the troposphere then closes at the appropriate atmospheric sound speed. Thus the K-T clay layer, which is observed to have ETC of up to 21%, represents only the prompt ejecta which is circulated meridionally on a time scale of a few days and latitudinally over a time for several months as it presumably rains down on the earth for a period of several years in analogy to ejecta from large volcanic explosions. The major energy input to the atmosphere which gives rise to worldwide $\sim 10^\circ\text{C}$ rise of the troposphere temperature is largely associated with the low speed ejecta which has a probably undetectably low fraction of ETC and would be expected to only be locally distributed.

GEOCHEMICAL ANOMALIES NEAR THE EOCENE-OLIGOCENE AND PERMIAN-TRIASSIC BOUNDARIES: F. Asaro, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, CA 94720, L.W. Alvarez, Physics, Computer Science and Mathematics Division, LBL, and Space Sciences Laboratory, University of California at Berkeley, Berkeley, CA 94720, W. Alvarez, Dept. of Geology and Geophysics, U.C. Berkeley and H.V. Michel, E. and E. Div., LBL.

In a neutron activation study of six deep-sea rocks (DSDP 149, cores 30 and 31) from near the Eocene-Oligocene boundary an iridium anomaly of ~ 0.5 ppb (core 31, intervals 1-2 and 3-4 cm) was found in exactly the same region where many microtektites were detected by Glass and Zwart (1). Cores 30 and 31 differ markedly in the abundances of many other elements, but most of the difference is related to the change in the CaCO_3 abundance. G. and Z. considered the microtektites to be part of the North American strewn tektite field (1). As the amount of Ir is much greater than expected from its abundance in tektites and the maximum reported density of the microtektites (1), the Ir was probably deposited independently of (but simultaneously with) the microtektites. H.C. Urey has suggested that bediasites (Texas tektites) were related to the Eocene-Oligocene changes and that both were related to the impact of an extraterrestrial object on the earth (2). If the object were sufficiently massive, such an impact would cause an explosion which would inject a dust cloud into the atmosphere (2,3,4,) and distribute Ir world-wide (3,4). If the average amount of such Ir were the same as that measured at site 149 and if the impacting object were chondritic in composition, the mass of the object would be in the range between comparable and a factor of 10 smaller than that suggested as the cause of the Cretaceous-Tertiary extinctions. It was suggested that objects significantly smaller than the latter would not cause major extinctions (3). Otherwise the more plentiful smaller objects impacting the earth would have caused more major extinctions than have been recorded. There are, however, 4-5 species of radiolaria which were reported to have disappeared at the microtektite horizon. (1,5)

A neutron activation study was made of 11 rocks from near Permian-Triassic boundary near Nanking China. A previously identified montmorillonite clay layer at or near the P-T boundary is much different in chemical composition than the rocks above and below. The most prominent anomaly (on a carbonate-free basis) in two samples of the clay layer is the very low Cr abundance (< 5 ppm). It is an order of magnitude smaller than in the Permian and Triassic rocks. Thorium, Hf and Cs are higher (\sim a factor of 2) and Ca is lower in the clay relative to the other rocks. No Ir was detected in any sample, and the upper limit was 0.5 ppb. Massive extinctions of species occurred at the end of the Permian period which were comparable to or larger than those occurring at the end of the Cretaceous. The lack of a detectable Ir anomaly does not invalidate an extraterrestrial impact as a trigger for the extinctions (3). If they were initiated by a comet impacting the earth, the comet would probably have a higher velocity than Apollo objects and a considerable content of ice. It then might produce an explosion comparable to that suggested as the cause of the Cretaceous-Tertiary extinctions and distribute perhaps two orders of magnitude less Ir. More sensitive Ir measurements are in progress to test this possibility.

- (1) Glass, B.P. and Zwart, M.J. (1979). *Geo. Soc. of America Bulletin* 85 1305.
- (2) Urey, H.C. (1973) *Nature (London)* 242 32.
- (3) Alvarez, L.W., Alvarez, W., Asaro, F., and H.V. Michel (November 1979) Lawrence Berkeley Laboratory Report LBL-9666 Revised 12-12-79.
- (4) _____, _____, _____, _____, (1980) *Science* 208 1095.
- (5) Maurrasse, F. and Glass, B.P. (1976) Caribbean Geological Conference, 7th, Guadeloupe 1974, Transactions, 205

SIGNAL EVENTS IN THE PRE-CAMBRIAN BIOSPHERE

S.M. Awramik, Department of Geological Sciences, University of California, Santa Barbara, California 93106

The pre-Cambrian history of life reflects evolutionary responses to changing environmental conditions as well as metabolic and reproductive innovations. The extent to which large body impacts might have affected the course of evolution during this period is unknown. Indeed, attempts at reviewing and synthesizing the 3×10^9 year history of pre-Cambrian life are inevitably incomplete, conjectural and probably will be shown to be wrong in the near future. Nevertheless, even with the limited knowledge available, some trends and events have become apparent.

Life on Earth probably originated some 4,000 Ma ago. This happens to coincide with an episode of megacratering. It is conceivable that this bombardment by extraterrestrial bodies influenced biopoesis through the introduction of organic materials and trace metals, by providing additional energy for chemical reactions, by creating and destroying labile compounds, and possibly by destroying any life that may have already evolved.

From the first evidence of life in the fossil record some 3,500 Ma ago to the first appearance of shelly fossils 570 Ma ago, the record is dominated by and biased towards photosynthetic microbes. This includes both planktonic and benthonic microfossils as well as organosedimentary structures (stromatolites) built by benthic microbes. Procaryotes dominate the first 2×10^9 years of the record. Such microbes are notoriously resistant to environmental calamities. Eucaryotes appear about 1400 Ma ago, and slowly rise to dominate the fossil record by 570 Ma ago and are more sensitive to large scale environmental changes.

Early in the Archean primary producers underwent a radiation and became well established as evidenced by the abundance of organic matter in the sediments. Stabilization of cratons 2800 to 2500 Ma ago resulted in shallow shelf environments which provided sites for increased primary productivity of benthic as well as planktonic microbes. Photosynthetic O_2 production probably greatly increased during this interval. The appearance of geologically significant levels of O_2 in the atmosphere is related to a balance of O_2 production by photosynthesis versus uptake of O_2 by reduced cations, primarily ferrous iron, stored in and introduced into the hydrosphere. Meteorites might have played a role in the introduction of ferrous iron. By 2,000 Ma ago, oxygenic conditions prevailed on the Earth's surface, profoundly affected the biosphere and set the stage for the evolution of eucaryotes. By 1400 Ma ago, eucaryotic algae appear, among them phytoplankters, and slowly begin to diversify. A perturbation in the phytoplankton record occurred 650 to 570 Ma ago as well as a marked decrease in the numbers of different kinds of stromatolites.

Tempting as it may be to look to the skies for inspiration and causes for environmental and biotic changes in the pre-Cambrian, the meagre data available do not lend themselves to large body impact cause and effect considerations.

INVESTIGATIONS OF THE SLATE ISLANDS CRATER-

Mark E. Bengtson

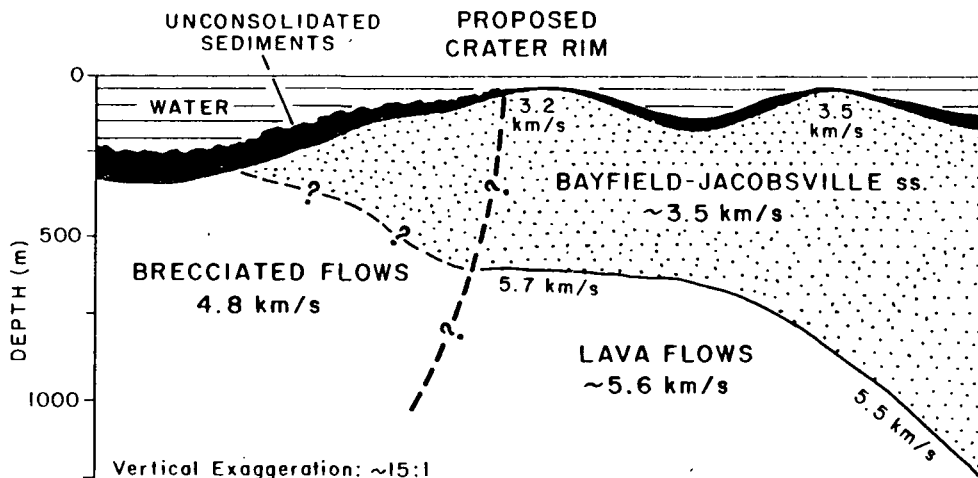
Robert P. Meyer (both at: Geophysical and Polar Research Center,
University of Wisconsin, Madison WI 53706)

Recent geophysical studies of the Slate Islands of Canada in northernmost Lake Superior have correlated observations of shock structures, cratering, and faulting with lowered seismic velocity under the crater due to brecciation at depth and consistent with intense deformation. We are attempting to determine not only the geophysical signatures of the Slate Islands complex, but also general diagnostics for the presence of cratering.

A survey of the crater area (defined by an irregular arcuate bathymetric rise) is now nearly complete. A close-order aeromagnetic survey (1000 yd. spacing, 425 m above lake level) and a set of marine magnetic and high-resolution 3.5 kc bottom and subbottom profiles taken under flight lines have shown several short wavelength anomalies on the east side of the islands. The sources of these anomalies appear to be 1/2 to 1 km below lake level, and none seem to have any bathymetric expression. To the west, a longer wavelength anomaly trending NW-SE has been delineated. This feature correlates well with a previously predicted igneous-sedimentary contact. The islands seem to be centered about a roughly defined arcuate magnetic high.

Digitally-recorded marine refraction and reflection records show large thicknesses (over 1 km) of a 3.5 km/sec layer underlain by a 5.5 km/sec refractor outside the crater. Inside the crater rim, the 3.5 km/sec layer is absent; here only a 4.8 km/sec refractor lying directly beneath unconsolidated sediments has been detected. This 4.8 km/sec refractor probably represents a brecciated zone of the 5.5 km/sec refractor.

A cross section based on the seismic data is shown below. Note that the lake bottom is much rougher inside the crater.



EXTINCTION AT THE END OF THE CRETACEOUS IN BOREAL SHELF SEAS - A MULTICAUSAL EVENT; Tove Birkelund, University of Copenhagen, Øster Voldgade 10, 1350 Copenhagen K, Denmark

Extinction data at the end of the Cretaceous is largely biased by coarsely defined biostratigraphic ranges and incomplete boundary sequences produced by major global marine regression. Further, most of the studied, essentially complete Cretaceous-Tertiary boundary sequences consist of continental slope and basinal pelagic limestones and turbidites with a well-documented microfossil record but a poor macrofossil record.

Highly fossiliferous, well studied, complete shelf deposits at the Cretaceous-Tertiary boundary are presently known only from Denmark (1). Outcrops in the central Danish Basin (northern Jylland) are the most complete; here, the boundary is marked by a marl layer up to 10 cm thick between pelagic white chalks. Towards the basin margin, a more complex hardground developed in shallower shelf limestones at the boundary, marking a minor disconformity which increases in magnitude shoreward, as at the classical Stevns Klint section which contains a strong Iridium anomaly in the boundary "fish clay" (2).

Detailed data on the biotic turnover at the boundary in Danish sections show: (A) Most characteristic Mesozoic marine macrofossil groups which became extinct at the boundary (ammonoids, belemnoids, a few bivalve groups) show a gradual decline through the Upper Cretaceous. The very last surviving species of these groups died abruptly at the boundary. (B) The great majority of known benthic organisms (bivalves, crinoids, asteroids, ophiuroids, echinoids, bryozoans, brachiopods, corals, benthic foraminifera) were affected by the extinction to varying degrees only at the species level. As presently known, 20-75 percent of the species in these groups cross the Cretaceous-Tertiary boundary. Some of these species "extinctions" were caused by slight changes in benthic facies. Among 45 bivalve genera occurring in the uppermost Maastrichtian, many of the genera that die out are older than the genera that cross the boundary. (C) Planktic foraminifera and coccolithophorids were strongly affected by the extinction event; detailed stratigraphic data in the most complete sections, however, show a gradual but rapid microbiotic turnover. In contrast, dinoflagellates were little affected by the extinction event. (D) The very earliest Danian deposits show an extremely significant, abrupt drop in density and diversity of benthic organisms immediately above the boundary. This drop is also seen in planktic foraminifera and coccolithophorids. Density and diversity of these organisms slowly increase again over a two meter interval of white chalk just above the Cretaceous-Tertiary boundary.

The extinction pattern in Denmark indicates a long-term change of the characteristic Cretaceous biota combined with a more abrupt but relatively minor extinction event at the Cretaceous-Tertiary boundary, followed by a short period of environmental stress. A number of major, long-term environmental changes combined with a minor catastrophic event should be considered as the cause of the terminal Cretaceous extinction.

- (1) Birkelund T. and Bromley R. G. (eds) (1979). The Maastrichtian and Danian of Denmark. Cretaceous-Tertiary Boundary Events Symposium I, p. 1-210.
- (2) Alvarez L. W. Alvarez W., Asaro F. and Michel H. V. (1980) Science 208, p. 1095-1108.

THE RELATIONSHIP OF COOLING, SUBSIDENCE, AND THERMAL STRESS TO THE TOPOGRAPHY AND TECTONICS OF MULTI-RINGED BASINS, Steven R. Bratt, Sean C. Solomon, Dept. of Earth and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, and James W. Head, Dept. of Geological Sciences, Brown University, Providence, RI 02912.

Many of the presently observed variations in the geometry and structure of multi-ringed basins probably reflect modification processes acting on time scales long compared to those for cavity excavation and ring formation (1). As a further step toward understanding the differences among the basins on the terrestrial planets, we have modelled the effects of the local thermal evolution of the basin region, including subsidence and thermal stress, and have applied several models to the basin Serenitatis.

We include two primary sources of initial heating of the basin subsurface above ambient temperatures: (a) conversion of impact kinetic energy into deeply buried heat (2,3,4) and (b) uplift of crustal and mantle isotherms during transient cavity collapse (5). Thermal histories for Serenitatis indicate that even by 10^8 yr, 10-20 percent of the initial heat remains in the basin region. The subsidence and thermal stress accumulated at the free surface during the complete cooling of the basin were calculated to have peak values on the order of thousands of meters and tens of kilobars, respectively. The locations of maximum compression and extension caused by basin cooling are dependent on the initial distribution of heat under the basin.

Models for the thermal evolution of large impact structures suggest that thermal displacement and stress can be significant contributors to the topography and tectonics of basins on time scales comparable to mare filling, lithospheric loading, and viscous relaxation. Also, the sensitivity of our models to the quantity and distribution of heat input under the basins might allow us to infer, from the observed topography and tectonics, something about the actual quantity and distribution of heat implanted during the impact process.

- References - 1) J. Head and S. Solomon (1981) LPSC XII, 424.
 2) M. Dence (1971) JGR, 76, 5552. 3) J. O'Keefe and T. Ahrens (1976) PLSC 7, 3007. 4) W. Kaula (1979) JGR, 84, 999.
 5) C. Thurber and S. Solomon (1978) PLSC 9, 3481.

PALEOMAGNETIC POLARITY STRATIGRAPHY OF THE CRETACEOUS/TERTIARY BOUNDARY, SAN JUAN BASIN, NEW MEXICO: R. F. Butler and E. H. Lindsay, Dept. of Geosciences, University of Arizona, Tucson, AZ 85721, N. M. Johnson, Dept. of Earth Sciences, Dartmouth College, Hanover, NH 03755

Paleomagnetic samples were collected at over 600 sites (3 samples/site) through the late Cretaceous to middle Paleocene age continental sedimentary sequence in the San Juan Basin. The sampled lithostratigraphic units include the Fruitland, Kirtland, and Nacimiento Formations as well as the Ojo Alamo Sandstone. Alternating-field demagnetization to peak fields of 200 to 300 oe was required to remove secondary components in order to reveal the polarity of the primary depositional remanence. Unambiguous polarity determinations were possible for almost all sites. Curie temperature and x-ray analyses on magnetic separates indicate that the magnetization is

carried by detrital titanomagnetite, $\text{Fe}_{3-X}\text{Ti}_X\text{O}_4$, of composition $X \approx 0.53$.

The resulting magnetic polarity zonation shows a strong correlation with the magnetic polarity time scale in the interval of anomalies 25 through 31. This correlation is strongly supported by the abundant vertebrate fossil occurrences and by a radiometric date of 64.6 ± 3.0 Ma from an ash layer in the late Cretaceous Kirtland Formation. Fossil mammals of Puercan (Early Paleocene) age occur in rocks deposited during magnetic anomaly 28, whereas mammals of Torrejonian (Middle Paleocene) age occur in rocks deposited during anomaly 26 and 27 plus the intervening reversed polarity interval. The Cretaceous/Tertiary boundary (recognized by the highest stratigraphic occurrence of dinosaurs) is at the midpoint of the normal polarity zone correlative with anomaly 29. This placement of dinosaur extinction in the San Juan Basin is significantly younger than the Cretaceous/Tertiary boundary of Gubbio, Italy. Therefore, extinction of dinosaurs in the San Juan Basin does not appear to coincide with the extinctions of the marine foraminifera which mark the Cretaceous/Tertiary boundary at Gubbio. This apparent diachroneity of the dinosaur and invertebrate extinctions at the close of the Cretaceous is inconsistent with catastrophic extinction models.

PATTERNS OF EXTINCTION AND SURVIVAL OF THE TERRESTRIAL
BIOTA DURING THE CRETACEOUS-TERTIARY TRANSITION

William A. Clemens, Dept. of Paleontology, Univ. of California, Berkeley,
California 94720

Catastrophic events of extraterrestrial origin, such as supernovae and asteroid impacts, have been cited as causal factors of the extinctions of many lineages of plants and animals used by biostratigraphers to mark the end of the Cretaceous. These and other hypotheses invoking catastrophic causal factors of terrestrial origin call for essentially instantaneous global extinctions of various groups of organisms. In contrast, other hypotheses suggest causal factors operating over a geologically short but biologically significant period of earth history (1). Detailed studies of local and regional patterns of extinction and survival among plants and animals provide an opportunity to test these two classes of hypotheses.

In most depositional basins the Cretaceous-Tertiary temporal boundary falls within significant gaps in the sedimentary and fossil records (see 2). However, in northeastern Montana strata of the Hell Creek and Tullock Formations contain a sequence of fossil localities recording the pattern of change in fauna and flora through the Cretaceous-Tertiary transition (3). Unlike most geological sections, the record is not interrupted by major gaps resulting from nondeposition or deposition followed by erosion (4). Detailed studies of local sections demonstrate that the extinction of dinosaurs and the change in flora used to mark the end of the Cretaceous occurred at different times. Patterns of extinction and survival at the close of the Cretaceous differed in flood plain and stream valley environments (5). On a broader scale, global analyses of terminal Cretaceous extinctions show that among plants the greatest decimation occurred in high latitude, temperate environments (6,7). In contrast, among marine invertebrates the highest frequency of extinction of lineages is found in tropical biotas (8).

The multiplicity of local and regional patterns of terminal Cretaceous extinctions strongly argues against any hypotheses invoking an instantaneous, global, catastrophic causal factor of either terrestrial or extraterrestrial origin.

- (1) Clemens, W.A., Archibald, J.D., Hickey, L.J., (in press) Paleobiology.
- (2) Matsumoto, T. (1980) Cretaceous Research, 1:359-373.
- (3) Clemens, W.A., Archibald, J.D. (1980) Mem Soc. Geol. France, 59:67-74.
- (4) Archibald, J.D. (in press) Univ. California Publs. Geol. Sci.
- (5) Archibald, J.D. (1981) Nature
- (6) Hickey, L.J. (1981) Nature
- (7) Hickey, L.J. (in press) In Berggren, W.A., Van Couvering, J.A., eds., Catastrophes in earth history: the new uniformitarianism. Princeton, Princeton Univ. Press.
- (8) Kauffman, E.G. (1979) In Christensen, W.K., Birkelund, T., eds., Cretaceous-Tertiary boundary events. Copenhagen, Univ. Copenhagen, v. 2, Proceedings, p. 29-37.

A FIRST-ORDER ESTIMATE OF VAPORIZATION IN OCEANIC IMPACTS: S.K. Croft,
Lunar and Planetary Institute, 3303 NASA Rd. 1, Houston, TX 77058

It has recently been suggested that the Cretaceous-Tertiary (C-T) extinctions may have been triggered by the impact of one (1) or more (2) objects (asteroids or comets) of kilometer dimensions. Climatological disturbances resulting from impacts are related to the amount of fine dust or vapor injected into the upper atmosphere. Roughly three out of four impacts on the Earth's surface occur in oceans, where vaporization of water is energetically easier than vaporization of rock in continental impacts. The amount of vaporization occurring in oceanic impacts has been investigated using a semi-analytical model of projectile penetration and pressure decay. The Model: 1) Shock heating is calculated assuming that the release adiabat is approximated by the Hugoniot (this assumption overestimates the amount of vapor produced). 2) Vaporization is assumed to begin in a volume element when the internal energy (IE) reaches $1.0\text{E}10$ erg/g, and is complete when IE equals $3.3\text{E}10$ erg/g. 3) The shock pressure geometry consists of a tangent-below spherical isobaric core of radius r_0 , surrounded by spherically concentric isobars of pressure, P , given by $P=P_0(r_0/r)^\gamma$. The spherical isobars approximate the angular dependence of pressure in the shock. The radius r_0 is derived from the 2-dimensional geometry of the release wave. The exponent γ is a constant related to the distribution of energy in material in and behind the shock. The model yields reasonable first-order estimates of the normalized volumes of melt and vapor produced as a function of velocity in impacts of iron (Fe) and gabbroic anorthosite (GA) meteorites on GA planetary crusts as calculated by (3) and (4). The model may be applied to other combinations of meteorite and crustal compositions by using the appropriate Hugoniot, density, and internal energy data.

Results: The volume of water vapor, V_w , generated in impacts of Fe, GA (asteroidal), and ice (cometary) objects into a water (w) half-space have been calculated. The ratio of V_w to the volume of rock vapor produced in a GA \rightarrow GA impact at an impact velocity, v , of 45 km/s (~ 13 projectile volumes, ref 3) produced by Fe, GA and ice projectiles of the same volume at the same v are: $\sim 1-3 \times (\text{Ice} \rightarrow w)$, $\sim 20-50 \times (\text{GA} \rightarrow w)$, and $\sim 60-230 \times (\text{Fe} \rightarrow w)$. V_w increases roughly as the square of v for all three meteorite compositions. For the special case proposed by (1) of the impact of a single, 10 ± 4 km diameter rocky object, the finite average depth of the ocean (~ 3 km) must be taken into account. At an impact velocity of ~ 25 km/sec, such an impact in the ocean would vaporize $\sim 8 \pm 4 \text{E}18$ g of water. A multiple impact event involving the same mass of meteorite as the single large object can vaporize a maximum of $\sim 4 \pm 2 \text{E}19$ g of water (assuming all vaporization occurs in the water layer). The approximate mass of water vapor in the Earth's atmosphere is $\sim 5 \text{E}19$ g (5). Consequently, a single impact C-T event will apparently increase the world water vapor supply by only 10-20%, whereas a multiple impact event may double it. Obviously, if the pieces of meteorite are small enough to detonate wholly in the atmosphere (as the Tunguska event), virtually no water vapor will be produced. Recognising that the climatological effects of the sudden production of large amounts of water vapor near the Earth's surface depend on many factors beyond the scope of this calculation, it is nevertheless clear that the extent of such effects is strongly dependent on the mode whereby the anomalous C-T material is delivered to the Earth's surface.

1. Alvarez L.W., Alvarez W., Asaro F. and Michel H.V. (1980) *Science* 208, 1095-1108.
2. Kyte F.T., Zhon Z. and Wasson J.T. (1980) *Nature* 288, 651-656.
3. O'Keefe J.D. and Ahrens T.J. (1977) *PLSC* 8th, p. 3357-3374.
4. Orphal D.L., Borden W.F., Larson S.A. and Schultz P.H. (1980) *PLPSC* 11th, p. 2309-2323.
5. Goody R.M. and Walker J.C.G. (1972) *Atmospheres*, Prentice-Hall, 150 pp.

SEARCH FOR LARGE BODY IMPACT CRATERS ON THE OCEAN FLOORS, O. Eckhoff, U.S. Naval Oceanographic Office, NSTL Station, Bay St. Louis, MS 39522; and P. Vogt, Naval Research Laboratory, Washington, D.C. 20375

A systematic examination of bathymetric charts and other geophysical data available at the Naval Oceanographic Office will be undertaken with the objective of identifying any large-body impact sites on the world's ocean floors; positive identifications, if any, and suspect features will be described in detail. It is not clear exactly what should be looked for, since no submarine impact craters are known. We are looking for more or less circular features in the 10-100km diameter class. Examples of suspect features is the the caldera-like Tore Seamount centered at 39.4°N, 13°W described by Laughton, Roberts, and Graves; and a caldera-shaped magnetic anomaly at 53°N, 19°W on the continental margin. The question of "where to look" can be subdivided into "what patch of ocean floor or subbottom is most likely to have been hit?" and "In what patch is the chance greatest for detecting - or having already detected - the topographic or other traces of an impact if it had occurred?" Clearly the older the ocean floor the greater the chances of having been struck: the oldest oceanic crust is about 180m.y. old; submerged continental crust may of course be much older. The second important variable is history of water depth: The shallower the water, the smaller the minimum body size leaving a perceptible trace on the bottom. Continental shelves and abnormally elevated oceanic crust (e.g. around Iceland) are therefore favored as most "vulnerable".

The probability of detection will increase with bathymetric data density. Most of the world ocean - particularly the southern hemisphere - averages less than 100km of randomly oriented sounding line per 30x30nm (55x55km) square; unsurveyed gaps even larger than 100x100km remain. circular crater-like features 15 to 50km in diameter could exist in the gaps between sounding lines; even if traversed by one or several tracks, a crater is unlikely to be identified as such unless the surrounding sea floor is comparatively smooth. The best chances of detection are in areas surveyed in detail by swath-mapping (multi-beam) techniques. Unfortunately only a modest fraction of the world ocean has been covered by such surveys to date.

The probability of detection will decrease with increasing topographic "noise": primarily the basement roughness produced by Mid-Oceanic Ridge accretion processes, and widely scattered subsequent volcanic overprinting by "mid-plate" or "hotspot" type volcanism. Since basement formed by slow sea-floor spreading (≤ 2.5 cm/yr half-rate) is roughest, the chances of detecting a crater, e.g. on the fast-spreading East Pacific Rise flanks, are greater than on coeval crust on the flanks of the Mid-Atlantic Ridge (except near hotspots like Iceland, where the basement is also smooth).

The probability of detection will also decrease with the amount of subsequent sedimentary, volcanic, or tectonic overprinting. However, if the overprinting reduces the relief, the chances of finding a post-overprinting crater are enhanced, particularly for flat-lying sediments with continuous acoustic reflectors, the disruption of which, by impact, would be easy to trace with seismic reflection methods. Craters on continental shelves and very shallow oceanic crust (e.g., Iceland) are very vulnerable to erosion and/or deep burial.

EVIDENCE FOR (OR AGAINST) A LARGE-SCALE IMPACT RESULTING IN A CATASTROPHIC EXTINCTION AT THE CRETACEOUS-TERTIARY BOUNDARY IN THE SAN JUAN BASIN, NEW MEXICO AND COLORADO; James E. Fassett, U.S. Geological Survey, Conservation Division, P.O. Box 26124, Albuquerque, New Mexico 87112

The rocks adjacent to the Cretaceous-Tertiary boundary in the San Juan Basin have been studied extensively of late with an eye to determining the correspondence--if any--between rock-stratigraphic contacts and the Cretaceous-Tertiary boundary. These studies have included physical stratigraphy, palynology, vertebrate paleontology, paleomagnetism, and trace element analysis. So far the results are inconclusive as to where the boundary is located, with pollen-and-spore data and vertebrate paleontological data suggesting differing placements of the boundary: if the palynologists are right, the dinosaurs lived into the Tertiary; if the vertebrate paleontologists are right, then a separate, distinct, and stratigraphically lower palynological Cretaceous-Tertiary boundary exists in the San Juan Basin.

A recent study of paleomagnetism in the southern San Juan Basin concluded with the thesis that deposition was continuous across the Cretaceous-Tertiary boundary, dinosaurs lived on into the Tertiary, and therefore, there could not have been a mass extinction resulting from an extraterrestrial impact at this boundary. This study, however, ignores overwhelming evidence for a hiatus representing some 2100 ft of eroded or missing rock section and encompassing all or most of Maestrichtian time.

A detailed search for the iridium-enriched layer at both the palynological and vertebrate paleontological boundaries at several localities in the San Juan Basin has thus far been fruitless. Work in the Raton Basin, in northeastern New Mexico, however, has disclosed an iridium-rich zone within 1 m of the pollen-and-spore Cretaceous-Tertiary boundary. If the iridium-rich zone in the Raton Basin did result from an extraterrestrial impact and, for the sake of argument, we accept this zone as the Cretaceous-Tertiary boundary and if we then infer that the Cretaceous-Tertiary boundary in the San Juan Basin coincides with the pollen-spore break, the conclusion is inescapable that the dinosaurs did live on into the Tertiary and that there was no mass extinction of vertebrates at the palynologic-iridium-zone, Cretaceous-Tertiary boundary in the San Juan Basin. Obviously, much more work is needed to resolve this question.

THERMAL EFFECTS OF LARGE IMPACTS. E. S. Gaffney, Los Alamos National Laboratory, Los Alamos, NM 87545.

Impact of large meteorites on a planetary surface can lead to increased heat loss by exposing hot material from great depths. Herbert et al. (1) and Minear (2) have discussed this effect for the lunar magma ocean and concluded that such an ocean would be a transitory phenomenon because of the enhanced heat flow. In this paper, the thermal effects of large impacts on a solid body are considered.

A large meteorite impacting the earth will form a transient crater with a diameter many times that of the meteorite and with a depth of about 20 per cent of the diameter. The ejecta will carry a large amount of thermal energy from the deeper portions of the transient crater; some of that energy will be lost to the atmosphere or to space and some will be deposited on the surface in the ejecta blanket. For craters 20 km or larger this ejected thermal energy can exceed the kinetic energy of the impact. Another large "convective" pulse will occur as the transient crater collapses, raising hot rock from beneath the transient crater to nearly the original surface level. On the earth, craters deeper than about 500 m (diameter greater than about 2.5 km) should collapse. The table indicates the magnitude of the energies involved. These values were obtained with a simple model using an initial thermal gradient of 50 K/km and initial heat flow of 90 mW/m². This large convective pulse which occurs on impact will lead to more rapid cooling rates (perhaps 50 to 100 per cent higher) than otherwise assumed in the late stages of planet formation.

Crater Diam. (km)	Impact Energy (J)	Thermal energy (J)		Excess heat flow (mW/m ²) after 10 ⁶ , 10 ⁷ , 10 ⁸ , 10 ⁹ yr
		in ejecta	in slump	
20	45x10 ¹⁸	58x10 ¹⁸	96x10 ¹⁸	41, 13, 4, 1
60	5.1x10 ²¹	6.6x10 ²¹	14x10 ²¹	65, 21, 6, 2
200	650x10 ²¹	920x10 ²¹	2210x10 ²¹	295, 93, 30, 9
600	62x10 ²⁴	100x10 ²⁴	120x10 ²⁴	544, 172, 54, 17
(D/d=2.5)	31x10 ²⁴	56x10 ²⁴	49x10 ²⁴	376, 119, 38, 12

Another effect, extending to later times, is the enhanced heat flow from the hot rock involved in the slump of the bottom of the crater. Using a simple slab cooling model (3) the excess conductive heat flow at the center of the impact would be substantial for many millions of years. After 10⁸ years, a crater 200 km or larger in diameter would have a heat flow 30 per cent above background. If this simple model applies, the thermal signature of an impact at the end of the Cretaceous might still be evident as a broad area of moderately high heat flow. The likely occurrence of convective (volcanic) heat transfer within the floor of the crater may lead to somewhat more rapid cooling.

References: (1) F. Herbert, M. J. Drake, C. P. Sonnett and M. J. Wiskerchen (1977) Proc. Lunar Sci. Conf. 8, 573. (2) J. W. Minear (1980) Proc. Lunar Planet. Sci. Conf. 11, 1941. (3) H. S. Carslaw and J. C. Jaeger (1950) Conduction of Heat in Solids, Oxford U. Press, Oxford.

LABORATORY SIMULATION OF PELAGIC ASTEROID IMPACT

By

Donald E. Gault* and Charles P. Sonett
University of Arizona, Tucson, AZ 85721

Despite recognition within the past two decades of the significance of extraterrestrial impact as a major geological process, and the identification(1) of almost 100 terrestrial structures up to 100 km diameter of impact origin(13 unequivocally)---the majority younger than 300 my---little attention has been devoted to pelagic events whose frequency must be at least some three-times greater. This inattention undoubtedly stems from the fact that water cannot preserve crater forms. For events sufficiently energetic to crater at abyssal depths, the resultant "hydroblemes" are obscured from easy detection by the overlying oceans; also, lifetimes are limited to the order of 10^8 years by reconstruction of the ocean floors. Pelagic events, nevertheless, portend equal if not greater geological importance than their continental cousins, both because of their greater frequency and because of important differences between water and land impacts, in particular the ease of vaporizing water relative to silicates for atmospheric/climatic effects, the generation of catastrophic waves propagating onto continental margins(2), and sea-water/magma reactions when "hydroblemes" penetrate through the thin ocean floor into the lithosphere.

Exploratory studies of such events made at NASA Ames Research Center, using the Vertical Gun Ballistic Range with water targets and pyrex spheres as projectiles at velocities up to 6 km/s, are reported(3) for impacts into "deep" water (depths 4X crater depths). Maximum crater depths and volumes are proportional, respectively, to $1/4$ and $3/4$ power of projectile kinetic energy. Collapse of the cavities produce central peaks with heights about equal to crater depths with gravitational potential energies of 3-4% of impact energy. Collapse of the peaks form secondary cavities and continued peak-cavity oscillations. Similar experiments in "shallow" water (depths \leq deep-water crater depths) produce cylindrical transient cavities which collapse and eject columns of water to indeterminate heights exceeding by at least a factor of ten the initial water depth. Both deep and shallow impacts produce a sequence of waves, the first forced by the rapid growth of the initial cavity, and subsequent waves (with velocities consistent with theory for shallow-water propagation) by collapse of peaks. Water deeper than at least $1/3$ of a deep water cavity prevented "hydroblemes" in the sand floor of the water tank, but erosion infill during cavity collapse prevent an accurate estimate of the true protective depth. Potentially significant effects of ambient atmospheric pressure on ejection/displacement of water during cavity growth have been observed, but such effects may be a scaling problem that may be avoided by maintaining energies above a critical value. Detailed application of these results to pelagic events will be presented.

(1) Grieve, R.A.F. & Robertson, P.B. (1979) *Icarus*, 38, 212-229; (2) Gault, D.E., Sonett, C.P. & Wedekind, J.A. (1979) *Lunar & Planet. Sci. X*, 422-424; (3) Gault, D.E. & Wedekind, J.A. (1978) *EOS (abs)* 59, 1121.

*Permanent address: Murphys Center of Planetology, 350 Main Street, Box 833, Murphys 95247

REDUCTION OF PHOTOSYNTHETICALLY ACTIVE RADIATION UNDER EXTREME STRATOSPHERIC AEROSOL LOADS, S. A. W. Gerstl and A. Zardecki, Los Alamos National Laboratory, Theoretical Division, MS-210, Los Alamos, NM 87545

The recently published hypothesis¹ that the Cretaceous-Tertiary extinctions might be caused by an obstruction of sunlight is tested by model calculations. First we compute the total mass of stratospheric aerosols under normal atmospheric conditions for four different (measured) aerosol size distributions and vertical profiles. For comparison, the stratospheric dust masses after four volcanic eruptions are also evaluated. Detailed solar radiative transfer calculations are then performed for artificially increased aerosol amounts until the postulated darkness scenario is obtained². Thus we find that a total stratospheric aerosol mass between 1 and 4 times 10^{16} g is sufficient to reduce photosynthesis to 10^{-3} of normal as shown on Fig. 1. Assuming that the dust mass ejected into the stratosphere (to altitudes higher than 10 km) is between 1 and 100 times the mass of the impacting asteroid³, we can infer that the impact of a 0.4- to 3-km diameter asteroid or a close encounter with a Halley-size comet is sufficient to create this darkness scenario and initiate the postulated C-T extinction mechanism. The diameter of 0.4 to 3 km defines thus a minimum asteroid size to cause global terrestrial extinctions if a continental impact is assumed.

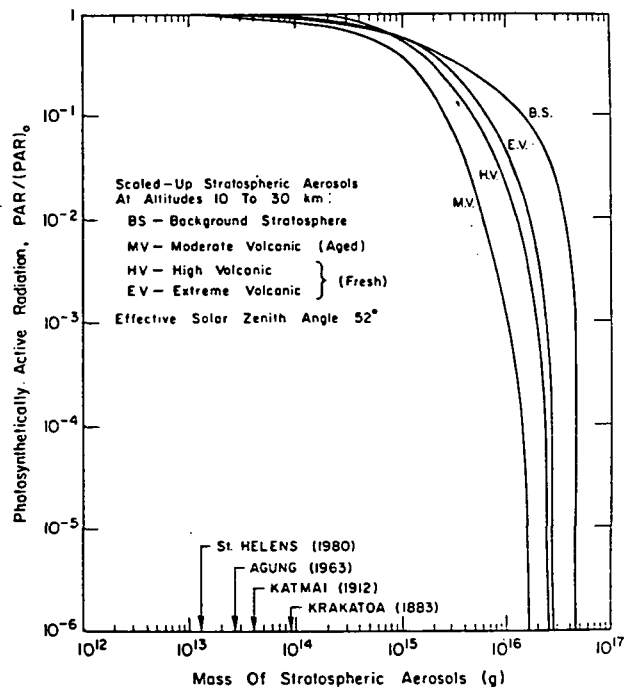


Fig. 1

Reduction of photosynthetically active radiation due to increased stratospheric aerosols for four different aerosol models.

1. L. W. Alvarez, W. Alvarez, F. Asaro, and H. Michel, Science 208, 1095-1108 (1980).
2. S. A. W. Gerstl and A. Zardecki, Los Alamos National Laboratory Report LA-8938-MS, Aug. 1981.
3. J. D. O'Keefe and T. J. Ahrens, Twelfth Lunar and Planetary Science Conf., March 16-20, 1981. Abstracts compiled by the Lunar and Planetary Institute, Houston, TX.

POSSIBLE CORRELATION BETWEEN TEKTITE FALLS AND OTHER EVENTS; B.P. Glass, Geology Dept., Univ. of Delaware, Newark, DE 19711

Although there is still some controversy, many workers believe that tektites were formed by large impact events. Microtektite distributions and abundances indicate that: The Australasian strewnfield covers $5 \times 10^7 \text{ km}^2$ and contains 10^{11} kg of tektite glass; and the Ivory Coast strewnfield covers $4 \times 10^6 \text{ km}^2$ and contains $2 \times 10^{10} \text{ kg}$. North American microtektites have been found in sediments extending halfway around the Earth. The limits of this strewnfield are not known, but present data indicate that it covers at least $5.7 \times 10^7 \text{ km}^2$ and contains at least $1.3 \times 10^{13} \text{ kg}$ of glass. The large quantity of glass and great extent of strewnfields suggest that the source craters must have been quite large. The source crater of the North American tektites, for example, was probably larger than 60 km in diameter. Previous work has shown that three of the four tektite events occurred at approximately the same time as reversals of the Earth's magnetic field. However, the North American tektite event does not appear to have been associated with a geomagnetic reversal. On the other hand, all four tektite events may have been associated with climatic changes. Oxygen isotope data (1) indicate that two of the largest drops in surface water temperature, within the last 60 m.y., occurred at the end of the Eocene and the middle Miocene. The temperature drop at the end of the Eocene occurred within 1 m.y. after the North American tektite event and may have been responsible for the extinction of several species of Radiolaria. Additional work is required to determine how closely these two events are associated. The character of the middle Miocene isotopic record suggests that about 14.8 m.y. ago (the approximate age of the Czechoslovakian strewnfield) the Earth's climatic system became extremely unstable and for 1 m.y. it oscillated back and forth between glacial and interglacial modes (2). Detailed isotopic records for the last 1 m.y. (3,4) indicate that the beginning of the Jaramillo geomagnetic event (time of the Ivory Coast tektite event) and the Brunhes/Matuyama reversal (time of the Australasian tektite event) correlate with drops in temperature. However, there are numerous temperature fluctuations within the last 1 m.y. and the temperature drops associated with the Jaramillo event and Brunhes/Matuyama boundary appear to be no different than the others. On the other hand, temperature fluctuations after the Brunhes/Matuyama reversal were greater than those prior to the Brunhes/Matuyama reversal (3), and the most conspicuous horizon of biostratigraphic change within the last 2.43 m.y. is at the Brunhes/Matuyama boundary (5). In conclusion, it appears that tektites are the result of large impacts which may have triggered reversals of the Earth's magnetic field and caused climatic changes, which, in turn, may have caused corresponding biological changes.

REFERENCES: (1) Shackleton, N.J. and Kennett, J.F. (1975) Initial Repts. DSDP XXIX, p. 743-755. (2) Woodruff, F. et al (1981) Science 212, 665-668. (3) van Donk, J. (1976) Geol. Soc. Am. Mem. 145, 147-163. (4) Shackleton, N.J. and Opdyke, N.D. (1976) Geol. Soc. Am. Mem. 145, 449-464. (5) Keany, J. and Kennett, J.P. (1972) Deep-Sea Res. 19, 529-548.

THE RECORD OF LARGE SCALE IMPACT ON EARTH. Richard A. F. Grieve, Department of Geological Sciences, Brown University, Providence, RI 02912*

There is abundant evidence that the earth has suffered large scale impacts throughout geologic time. Approximately 100 impact structures with diameters > 1 km are currently recognized (1). With the exception of Sudbury and Vredefort ($D \sim 140$ km), and Janisjärvi ($D \sim 14$ km), all known structures are Phanerozoic in age. Variations in their state of preservation indicate that, unless protected by a post-impact sedimentary cover, a structure with $D < 20$ km will be removed by erosion in ~ 600 my. Known structures are concentrated in the cratonic and associated areas of platform sediments in N. America and Europe. From the size-frequency distribution of structures in these areas, a terrestrial cratering rate of $0.35 \pm 0.13 \times 10^{-14} \text{ km}^{-2} \text{ y}^{-1}$ can be calculated for craters with $D > 20$ km (2).

The transition from simple bowl-shaped craters to shallower complex structures with uplifted central peaks and/or rings occurs on earth at $D \sim 4$ km and $D \sim 2-3$ km for crystalline and sedimentary targets, respectively. The cratering process is fairly well established for simple craters (3), but is less well understood for complex structures (4). It has been suggested that complex structures are produced by low density cometary bodies (5). This hypothesis finds little favor in studies of the siderophile contents of impact melt rocks which correspond to that part of the target shock-melted by pressures ~ 600 kb. Siderophile enrichments or Fe-Ni spherules have been recognized in ~ 15 structures and intensive studies suggest that various types of stones and irons can produce both simple and complex structures (6).

From energy partitioning studies and the volumes of impact melt, as well as comparisons with craters produced by nuclear and chemical explosions, energy scaling laws of the type $D \propto KE^b$, where KE is projectile kinetic energy, have been derived. For large structures, the exponent b lies between 3.4 and 4. Structures the size of Manicouagan and Popigai ($D \sim 100$ km) require impact energies of $\sim 10^{29}-10^{30}$ ergs (7), corresponding to 1-2 orders of magnitude more energy than the annual output of internal energy of the earth being released at one spot on the earth's surface in a time span of seconds. Most of the energy is contained in the formation of the crater and producing shock lithologies, such as impact melts, and the identifiable geologic effects of known impact events are generally local. It has been suggested that the Sudbury event, ~ 1.7 by ago, gave rise to endogenic magmatic activity and that basin-sized impacts on the pre-4.0 by earth may have produced long-lived geological anomalies which gave rise to or accentuated the dichotomy between continental and oceanic crust (8,9). Biological or climatological changes as a direct consequence of impact are difficult to prove. Correlations between impact-related tektites, geomagnetic reversals and extinctions have been suggested (10). The problem is that the cratering record is incomplete due to sampling, geologic activity, and the fact that the earth's surface is $\sim 70\%$ ocean. The precision of radiometric dating of impact events is also relatively poor. For example, the biological extinctions at the end of the Eocene (34 my) are within the uncertainty attached to the Popigai impact (38 ± 9 my). Similarly, there is no known structure correlated with the Cret.-Tert. extinctions, for which geochemical evidence suggests an extra-terrestrial cause (11); although there are 5 known structures with ages of 65 ± 5 my.

REFERENCES: 1) Grieve R.A.F. and Robertson P.B. (1979) *Icarus* 38, 212-229; 2) Grieve R.A.F. and Dence M.R. (1979) *Icarus* 38, 230-242; 3) Roddy D.J. et al. (1977) *IEC*⁺; 4) Schultz P.H. and Merrill R.B. (1981) *PLPS* 12A (in press); 5) Roddy D.J. (1979) *PLPSC* 10th, 2519-2534; 6) Palme H. et al. (1981) *GCA* (in press); 7) Dence et al. (1977) *IEC*⁺, 247-275; 8) Frey H. (1980) *PreC. Res.* 10, 195-216; 9) Grieve R.A.F. (1980) *PreC. Res.* 10, 217-248; 10) Glass B.P. et al. (1979) *PLPSC* 10th, 2535-2545; 11) Alvarez L.W. et al. (1980) *Science* 208, 1095-1108. *IEC*⁺ Impact and Explosion Cratering. Pergamon, N.Y. *Permanent address: Earth Physics Branch, Ottawa, Canada K1A 0Y3.

THE SOUTHERN GULF OF ST. LAWRENCE AS AN IMPACT STRUCTURE:
A PRELIMINARY INVESTIGATION

Jack B. Hartung, NASA Johnson Space Center, Houston, Texas 77058

A preliminary investigation produced information interpretable in terms of an impact origin for the southern Gulf of St. Lawrence.

The circular shoreline of the Gulf has led to the suggestion of its impact origin. Prince Edward Island may be related to a partial concentric ring. Topographic contours much above or below sea level, however, do not yield corresponding circular patterns.

Gravity and magnetic intensity contours over the Gulf enclose broad irregular areas. Correlation is poor between gravity and magnetic data. Anomalies are relatively small. Seismic refraction data yield depth-to-"basement" information which shows a greater depth to "high-velocity" material for the east half of the southern Gulf than for the western part. Comparison with onshore geophysical data, which has a higher spatial resolution, suggests that a more complex structure exists beneath the southern Gulf than has so far been delineated using available data. The lack of circular symmetry for geophysical data is consistent with an impact hypothesis if the data are controlled by the different characteristics of rocks present before the presumed impact.

No petrographic or other features, such as multiple sets of deformation lamellae, shatter cones, meteorite fragments, or suevite-like rocks, have been found in areas close to the Gulf.

The circular pattern of the southern Gulf is superimposed upon the intensely deformed early Paleozoic rocks involved in the Taconic orogeny. After the Taconic orogeny and before middle-to-late Devonian time a region extending outside the present Gulf was fractured or "shattered" on scales of up to tens of kilometers. Subsequent Devonian-Carboniferous history involved widespread block faulting as large areas of "basement" rock moved vertically and separately to achieve new equilibrium levels. At the same time a large inland lake had formed. Conglomerate-rich continental sediments together with a variety of extrusive volcanic rocks were deposited around the lake followed by increasingly finer-grained red beds and finally evaporite deposits within the subsiding basin. A widespread rapid change to normal marine limestone indicates flooding by sea water of a large area which was previously below sea level. This sequence of events may have been initiated by a large impact in Devonian time causing nearby rocks to "shatter" and producing a basin which subsequently subsided under an increasing load of sediments. Evidence relating to this hypothesis may be found most likely in the oldest sediments in the basin: the Fisset Brook formation on Cape Breton Island, the McAras Brook formation and possibly the Malignant Cove formation on mainland Nova Scotia, and the Memramcook formation in New Brunswick. The base of these units is a polymict conglomerate containing unsorted, angular clasts and might be considered the least reworked, but not unreworke, ejecta deposits associated with a large impact.

The author is a National Research Council Senior Post-doctoral Research Associate and acknowledges helpful discussions with C. Beaumont, D. E. Gemmell, R. Gibbons, P. S. Giles, J. B. Hamilton, R. T. Haworth, R. D. Howie, and S. McCutcheon.

PALEOCLIMATIC SIGNIFICANCE OF HIGH IRIDIUM
CONCENTRATIONS IN PLEISTOCENE DEEP-SEA SEDIMENTS,
James D. Hays, Lamont-Doherty Geological Observatory
and Department of Geological Sciences, Columbia
University, New York, NY 10027

High concentrations of iridium, ranging from 0.83-7.6 ppb on a carbonate free basis, have been reported from a subantarctic deep-sea core (E21-17).

Preliminary analysis of the radiolarian assemblage in this core does not indicate any unusual climatic response associated with the high iridium levels. This suggests that either the resolution of the paleoclimatic analysis is insufficient to detect a short lived climatic change or that large extraterrestrial impacts can occur without causing a detectable climatic change or that high iridium concentrations in sediments may be caused by sedimentary processes and are not necessarily related to cataclysmic extraterrestrial events.

LAND PLANT CHANGE ACROSS THE CRETACEOUS-TERTIARY BOUNDARY Leo J.

Hickey, Div. of Paleobotany, Smithsonian Institution, Washington, D. C. 20560

Land floras show no pattern of overall, dramatic extinction across the Cretaceous-Tertiary (K/T) boundary as would be expected from the more extreme of the "cosmic impact" theories recently proposed. Middle and late Cretaceous vegetation was dominated by the flowering plants that appeared early in the period and began to diversify into archaic groups only distantly related to modern forms. Angiosperm dominance was achieved by the Turonian Stage in the Northern Hemisphere but may have been delayed until the Maastrichtian in the Southern Hemisphere. Starting in the mid-late Cretaceous the pollen flora of the middle to higher latitude Northern Hemisphere became markedly provincial with Eastern North America and Europe dominated by the Normapolles group and Western North America and Siberia dominated by the Aquilapollenites group.

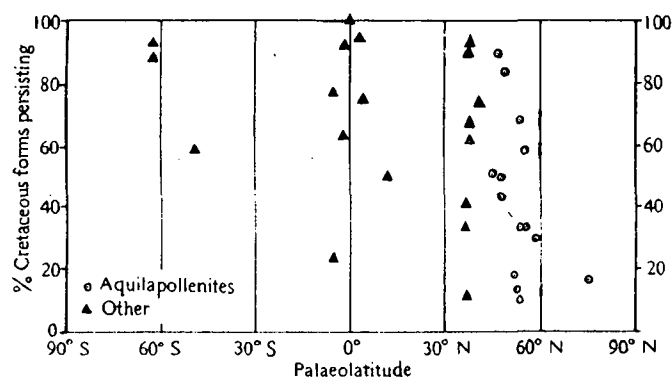


Fig. 1 Survival of Cretaceous land plant species (mainly angiosperms) across the K/T boundary as a function of paleolatitude. Aquilapollenites Province shown by circles.

At the end of the Cretaceous, the most noteworthy change in the land flora was the decimation of the Aquilapollenites Province (Fig. 1). Within its boundaries, extinction often amounted to 75% of Cretaceous species and showed an imperfect pattern of increase toward the north. Elsewhere the level of extinction was much less, seldom exceeding 50%, with levels in the tropics and Southern Hemisphere much lower still. Floral diversity shows parallel changes in addition, the late Maastrichtian pollen record of Western Canada and the Northwest United States shows a decrease in diversity and a shift toward seasonal and cooler-climate types. The less well analyzed leaf record across the K/T boundary is compatible with the pollen record in its level of extinction (40% to 60%) and shift toward forms whose serrate margins indicate cooler climates. For comparison, levels of extinction at the Paleocene-Eocene boundary were 30% for the pollen and 50% for the megaf flora in North Dakota and Wyoming. The generally moderate, geographically variable pattern of land plant extinction and the diachronism of plant-dinosaur extinctions at the close of the Cretaceous make it unlikely that a universal biotic catastrophe occurred. The most plausible explanation for this pattern appears to be long-term climatic deterioration perhaps accentuated by the effect of widespread marine regression at the end of the Cretaceous.

LARGE BODY IMPACT AND THE PRE-CAMBRIAN:
NEED FOR MULTIPLE ORIGINS OF LIFE?
Richard C. Hoagland, Hoagland Scientific
331 62nd St. Oakland, CA. 94618

One 10km Apollo/Amor object impacting approximately every 100 million years during the pre-Cambrian, could have resulted in all life being "wiped out" at several crucial stages, necessitating its re-origin many times during this long period. The mechanism envisaged is that proposed by Alvarez et al for the Cretaceous extinctions, i.e., a dust "sunscreen" suspended in the stratosphere for several years. This admittedly revolutionary proposal gains credibility from another revolution currently taking place in primitive Earth geochemistry: ideas ranging from Ableson (1966) to recent computer studies by Chang, Pinto, Gladstone and Yung, which find that Earth's present atmosphere -- minus the free oxygen -- is sufficient to recreate significant yields of essential pre-biotic organics, given present energy resources and a few million years.

Even if not catastrophic to all microbial life, the repeated "turning off" of the sun would have struck a devastating blow at newly-evolved photosynthesizing bacteria and blue-green algae, forcing repeated evolution of such crucial forms. Only when evolution developed several "work arounds," beginning with a photosynthetic form capable of switching between photosynthesis and chemosynthesis, it is argued, could life proceed past simple one-celled bacteria. Evidence is cited, such as the enigmatic "banded iron formations" (BIF), supporting the idea that oxygen-emitting organisms suffered repeated "die offs" during the first 2 billion years of their existence. The final disappearance of the BIF and the appearance of key minerals, formed only in the presence of free oxygen, both at about 2 billion years BP, is identified as the point when such a biochemical "invention" was successfully accomplished. The role of impacts on oceanic chemistry is also examined. It is calculated that an ocean impact, in the thin crust overlying the mantle, would have exposed more than enough primitive material to critically affect the acid balance of the oceans -- leading to several critical events, including the "tuning off" of the calcium carbonate test-making process through a literal "acid rain" worldwide. The possibility that this was a factor in the sudden appearance of such shell-making at the dawn of the Cambrian is also raised.

These proposals hold important implications for many factors previously regarded as "known" about the possibilities for extra-terrestrial life -- including the possibility that different solar systems, with a differing arrangement of Jovian-type planets, could have radically differing histories of major impacts on terrestrial-type worlds. In some systems, with a lower impact rate, life -- and intelligent life -- could develop far more quickly than on Earth, with it's 4 billion years of evolution. This raises the interesting prospect that much brighter stars, with much wider "habitable zones," should be targets for SETI-type projects now beginning.

SCALING CONSIDERATIONS FOR KILOMETER-SIZED IMPACTORS

K. A. Holsapple, University of Washington FS-10, Seattle, WA 98195

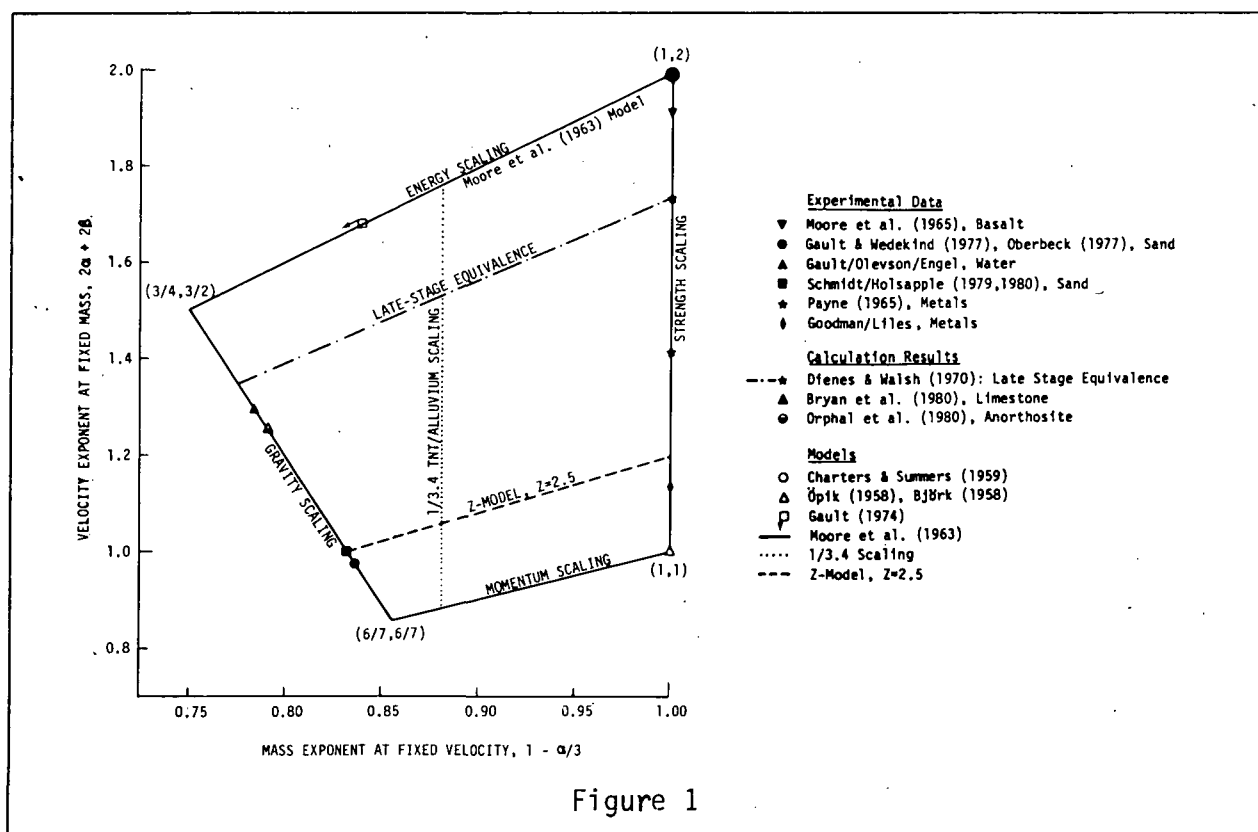
Estimates of the effects of large-body terrestrial impacts require at the outset estimates of the crater and ejecta magnitudes due to a given impactor. Scientific observations of impacts with known conditions are limited to small-scale laboratory tests. Explosive cratering tests in common geologies include only a few events as large as a kiloton of equivalent TNT. Consequently, it is necessary to rely on scaling laws to extrapolate to kilometer-sized impactor events.

Some results from a theoretical study (1) of scaling laws for impact cratering that has recently been completed are presented. Possible scaling laws are shown to be bounded by well-defined limits, based upon plausible physical assumptions. Special cases of these bounds correspond to degenerate special scaling laws found in the literature, including cube-root and quarter-root cases. It is shown that, contrary to statements in the literature, quarter-root scaling need not be the gravity-dominated limit for large sizes.

A survey of scaling results obtained by experiment, calculation, or theoretical arguments, for a variety of geological and structural materials that are found in the literature are compared to the derived bounds (Fig. 1). All results are on or within the bounds. The comparison of all such scaling laws in this common framework makes clearer the relationships, generality, and applicability of existing scaling laws.

The application and choice of scaling laws for large-scale impact events is discussed. The current thinking versus certain examples in the literature is emphasized. Past practice has resulted in estimates of crater size for a given impactor that are far larger than current results indicate.

Reference. (1) Holsapple, K. A. and Schmidt, R. M. (1981) "On the scaling of crater dimensions 2. Impact process" Accepted for publication in J. Geophys. Res.



ATMOSPHERIC EFFECTS OF LARGE-BODY IMPACTS: THE FIRST FEW MINUTES;
Eric M. Jones, Maxwell T. Sandford II, and Rodney W. Whitaker

Hypervelocity, large-body impacts with the Earth will impart significant energy to the atmosphere via several mechanisms. First, the air is heated by the formation of, and contact with the bow shock. For an object moving at 20 km/s the air is heated to about 10^5 K. Second, if the impacting object shatters in the air its kinetic energy will be deposited almost instantaneously - producing an intense atmospheric explosion. The 1908 Tunguska explosion is probably an example of meteoritic detonation. Third, impact with the ground will vaporize much of the projectile and a considerable mass of the target rocks. The explosive expansion of these hot vapor products will create a significant atmospheric fireball. Fourth, any solid ejecta will deposit energy in the air through drag and conductive heating, and vaporized debris may cool and precipitate from the atmosphere. Finally, impact in the ocean will create a steam explosion with considerable atmospheric consequences.

The prompt deposition of large amounts of energy near the earth's surface produces significant atmospheric effects. Jones and Sandford (1977) previously described a calculation of a 500 megaton (2.1×10^{25} erg) point explosion on the surface which, by two minutes, produces a hole in the atmosphere 65 km in radius. Such deposition would represent five percent of the energy of a 10 gigaton (4.2×10^{26} erg) impact.

This paper presents a new calculation with initial conditions which more closely approximate the atmospheric deposition by a large-body impact. Specifically, we have modeled the detonation source as a 55 meter-thick disk 1.5 kilometers in radius. The disk is composed of air at 10^5 degrees Kelvin, 6 grams per cubic centimeter density and initially moving upward at 20 kilometers per second. Such conditions could be produced above a 20 km/s geologic piston. The source disk contains 500 Mt of energy.

By about 1 second the initial flow had evolved to a nearly spherical blast wave and subsequent evolution is expected to resemble the previous calculation.

Additional calculations which model atmospheric effects of large impacts according to a two-phase flow (dust and gas) hydrodynamic formulation are in progress. A calculation of an ocean impact is also being considered.

Jones, E. M. and Sanford, M. T. II, (1977) in Impact and Explosion Cratering, p. 1009-1024. Pergamon Press, New York.

GRADED EXTINCTIONS RELATED TO BROAD ENVIRONMENTAL DETERIORATION IN THE CRETACEOUS; Erle G. Kauffman, Department of Geological Sciences, University of Colorado, Campus Box 250, Boulder, CO 80309, U.S.A.

The Cretaceous-Tertiary boundary is broadly viewed as representing a mass global extinction of structurally and ecologically diverse organisms within a very short time period. Theories generated to explain this biotic "crisis" focus on single catastrophic causes - meteorite impact, extraterrestrial radiation, rapid chemical and temperature changes in the oceans or atmosphere, etc. But whereas many organisms do become extinct at or near the Cretaceous-Tertiary boundary, the global "catastrophic" aspect of the extinction is largely an artifact of stratigraphic preservation, or coarse resolution and plotting of biostratigraphic data. Over 90 percent of the world's boundary sequences, as preserved, are marked by abrupt biological change which is primarily a reflection of boundary disconformities omitting 0.5 - 5 MY of latest Cretaceous and Paleocene history, not an "extinction event." Even within complete or nearly complete marine boundary sequences the extinction record is poorly preserved (Denmark excepted) because of the predominance of slope and shelf depth pelagic facies lacking diverse macrofossils. The biotic history of the Late Cretaceous, therefore, is not well enough preserved or documented to hypothesize about the magnitude, timing, extent, and causes of extinction except for the microplankton, which generally show a rapidly graded extinction among calcareous plankton just below and at the Cretaceous-Tertiary boundary but minor extinctions (mainly species) among noncalcareous plankton. Detailed documentation of the stratigraphy, paleoenvironments and whole biota at numerous localities where they are well preserved and contain both micro- and macrobiota produced the following observations which contradict the catastrophic view of the terminal Cretaceous extinction. (1) During the last few MY of the Cretaceous stratigraphic and geochemical data suggest broadly deteriorating global environments, especially in the marine realm, including a major eustatic drawdown, regression of epicontinental and shelf seas, loss or great restriction of many marine shallow water habitats, widespread temperature and possibly salinity fluctuations in world's oceans, spread of anoxic zones (benthic, midwater), changes in current patterns and heat distribution over both marine and terrestrial environments, etc. Increasing stress on marine and continental organisms is indicated. (2) Near-catastrophic extinction of organisms at or near a peak in their evolutionary diversification occurs only among calcareous microplankton of warm water marine habitats; associated non-calcareous plankton and nearly all other plants and animals that die out at or near the end of the Cretaceous show graded extinction histories linked to phases of environmental decline and biotic competition during the last 1-30 MY of the Cretaceous; these include many characteristic Cretaceous groups such as the ammonoids, belemnoids, inoceramid and rudist bivalves, hermatypic corals, larger forams, etc. which were well into evolutionary decline and represented by only a few generalized species and genera at the end of the Cretaceous. (3) Among all major marine groups, more rapid and significantly greater extinction levels occur in the Tropics; the magnitude of the Cretaceous-Tertiary extinction gradually diminishes toward the poles. Thus, convergence of many deteriorating environmental events mainly accounts for Late Cretaceous marine and continental extinction by increasing stress levels beyond the reproductive and lethal niche limits of many characteristic Cretaceous organisms. Surviving groups, weakened by environmental decline during the Late Cretaceous, were vulnerable to the terminal "event" that so dramatically annihilated the calcareous microplankton at the boundary. Whatever the cause of this event, it was of relatively minor importance in explaining Cretaceous extinction. This is proven by tests of large rapid intra-Cretaceous extinctions lacking evidence for catastrophic "events."

A LARGE-SCALE POSITIVE-GRAVITY ANOMALY IN NORTHEASTERN NORTH AMERICA: POSSIBLE EVIDENCE FOR LARGE-SCALE METEORITE IMPACT John S. Klasner, Dept. of Geol., Western Illinois University and U.S. Geol. Surv., Macomb, IL 61455; Wm. F. Cannon, U.S. Geol. Surv. National Center, MS. 954, Reston, VA 22092; K. J. Schulz, Dept. of Earth and Planetary Sciences, Washington Univ. and U.S. Geol. Surv., St. Louis, MO 63130

The Bouguer gravity anomaly map of northeastern North America has a large-amplitude positive-gravity anomaly of roughly 2,500 km. that encompasses the Superior Province of the Canadian Shield. It has a central low encircled by an annular zone of high gravity that decreases outward from about -20 to -70 mgals. The anomaly is interrupted by gravity signatures associated with the Grenville Province and Keweenawan rift and a positive gravity anomaly over Hudson Bay. Concentrically arranged foldbelts of Proterozoic X rocks are parallel to the circular pattern. Most diatremes, kimberlite intrusions, carbonatite, and ultramafic bodies of the Superior Province lie beneath the annular high suggesting deep-crustal or upper-mantle petrologic affinities. Radiometric dating of Archean rocks indicate that the oldest rocks (ca. 3.4-3.8 b.y.) are found toward the outside of the gravity anomaly. There is no readily apparent near-surface feature that explains the total anomaly, thus suggesting that a large subjacent body of excess mass exists beneath the Superior Province. The major difference between the terrestrial anomaly and lunar mascons (1) is the central low associated with the earth's anomaly. A two-dimensional gravity model and hypothetical geologic cross section have been constructed to approximate crustal structure beneath the anomaly. Crustal thickness is on the order of 30 to 35 km. with the thickest part in the center. The gravity high is attributed to uplift of 3.0 gm/cc deep crustal rock beneath the center of the anomaly and to intrusion of relatively dense masses of ultramafic rock, carbonatite, and other rocks of deep crustal affinity into the upper crust. The central gravity low is attributed to low density, subjacent granitic plutons mostly associated with greenstone-granite terrane. Intermediate density (2.8 gm/cc), tonalitic crust thickens outward from the central region of the gravity high to about 27 km. near the edge. Higher frequency positive-gravity anomalies are superimposed on the broad gravity high at the position of Proterozoic X basins.

The crustal gravity and geologic model agrees well with previously proposed meteorite impact models (2,3) of crustal evolution and structure. The intensely fractured central part of the impact structure is the area of highest gravity where dense basal crust is uplifted and intrusive bodies of deep crustal or upper mantle affinities are intruded into the highly fractured upper crust. Late stage felsic igneous activity following impact results in formation of subjacent granitic plutons and zones in the greenstone-granite terrane, mostly beneath the central low. Intermediate-stage igneous activity results in formation of relatively old tonalitic-gneissic crust. The oldest rocks are found toward the outer edge of the impact structure where the crust was least disturbed and where thermal and tectonic stability was most likely attained soon after impact relative to the central region. In structures of this size, however, an anomalous thermal regime may continue for as long as 10^9 years (3) below the major impact basin.

Muller, P. M. and Sjogren, W. L., 1968, *Science*, 161, p. 681-684.

Weiblen, P. W. and Schulz, K. J., 1978, *Proc. Lunar Planet. Sci. Conf.* 9th, p. 2749-2771.

Grieve, Richard A. F., 1980, *Precambrian Research*, 10, p. 217-247.

GEOCHEMICAL EVIDENCE FOR MAJOR ACCRETION EVENTS. Frank. T. Kyte and John T. Wasson, Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90024

The discovery of anomalous concentrations of Ir (1) and other siderophiles (2-4) at the Cretaceous-Tertiary (K-T) boundary has resulted in the hypothesis that the terminal Cretaceous extinctions were the direct result of a major accretionary event. Accretion mechanisms proposed are impact of a chondritic (1) or iron (4) asteroid, a comet (5), or tidal disruption and subsequent accretion of numerous cometary fragments(4). Testing of these accretion models is exacerbated by the paucity of data on the marine geochemistry of Ir and the other siderophiles, as well as their steady-state abundances in pelagic sediments.

Of all these models, the simplest to test is the asteroid impact. Such an impact would create ejecta containing both projectile and target materials. This component should differ from both meteoritic materials and normal pelagic sediment. For example, ejecta from an oceanic impact should contain a substantial mantle component, causing Mg, Ni, and Cr enrichments in the horizon. The impact model can be confirmed by showing that this uniform terrestrial signature is present in the K-T boundary worldwide.

Ruling out an iron meteoroid source is not simple. Since an asteroid core contains virtually all the noble metals from its parent body, abundances for these elements will be nearly identical to those of the chondritic parent. An element that has a high concentration in chondrites but is low in both iron meteorites and the Earth's crust is Cr, but Cr is high in mantle rocks and in some marine sediments.

The tidal disruption model is the most difficult to test. In this case, numerous small impacts are possible but the terrestrial ejecta component should be minor to negligible. Enriched horizons should contain only the meteoritic source and pelagic sediments that are more-or-less typical for the locality. Another possible confirmatory observation would be numerous small craters at 65 Ma.

Another, more indirect, test of these and other models is to analyze for Ir in sediments from other times. We have initiated a search for Ir anomalies, particularly in an abyssal clay giant piston core which contains a sedimentary record for the entire Cenozoic. If new Ir anomalies can be found, their detailed characterization may allow us to resolve the different kinds of accretion processes. For example, if Ir concentrations can be correlated to microtektite horizons or the Popigai impact, this would indicate whether it is possible to get the high projectile components in impact ejecta as observed in K-T sediments (4). Additionally, measurements of background values can determine whether the overall flux of extraterrestrial materials varies with time.

- (1) Alvarez L.W., Alvarez W., Asaro F. and Michel H.V. (1980) Science 208, 1095-1108.
- (2) Smit J. and Hertogen J. (1980) Nature 285, 198-200.
- (3) Ganapathy R. (1980) Science 209, 921-923.
- (4) Kyte F.T., Zhou Z. and Wasson J.T. (1980) Nature 288, 651-656.
- (5) Hsu K.J. (1980) Nature 285, 201-203.

ROCHECHOUART: GEOCHEMISTRY. P. Lambert, Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287.

Previous geochemical investigations of Rochechouart focussed on trace elements (1,2,3) after the recognition of the meteoritic contamination of Rochechouart breccias (4, 5). This study is devoted to major elements. Details on the geology, structure and petrography of Rochechouart are given in (6-9). 93 samples from the basement (A) including 20 samples from autochthonous breccias (B) have been studied, with 43 glass free mixed breccia (C), 50 suevite like breccias (D), and 95 impact melts (E). In addition, 20 clasts of the different target formation embedded in the impact melt were separated and analyzed. 116 samples were analyzed by wet chemical analysis and/or X-ray fluorescence X for 13 elements, and 200 were studied by atomic absorption spectrometry for only Fe^{2+} , Fe total, Mg, Na, K (and trace Ni-Co).

Results = 1): Exposed basement formations have a granitic composition; 2) Two chemical groups are distinguished in the basement, gneiss and granites *sensus largo* (s.l.) which includes granites, leptynites and microgranites; 3) the different breccias have granitic composition and are unlikely to be formed by other materials than those actually exposed in the basement; 4) the plausible average target composition range between gneiss 50-95%, granites s.l. 50-5%; 5) Si and Al are the least affected elements by the impact and/or post impact events. Their overall fluctuation is less than 10%; 6) Impact melts are strongly enriched in K (150-200%) and Fe^{3+} (20-80%) and depleted in Ca (80-85%), Na (95-90%), Fe^{2+} (85-90%), and Mg (35-70%); 7) Similar anomalies are found in other breccias. The amplitude of these anomalies follows the trend $E > D > C > B > A$. This trend was also observed for the meteoritic contamination (1,2,4; 8) $\text{Fe}^{3+}/\text{Fe}^{2+}$, alkalis and Mg anomalies are also found in basement clasts in E. The amplitude of those anomalies is similar in the melt and in the clast fraction of E, from which it is deduced that the anomalies are not directly controlled by shock conditions; 9) standard deviations on analyzed elements of the different breccias are very similar to those obtained for the basement formations. This suggests the mixing process involved in the formation of each allochthonous breccia is very different.

	N	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O
Gneiss	16	66.39	0.86	16.30	3.11	2.37	2.78	1.87	2.92	3.35
s.d.		4.3%	18.6%	10.1%	44.2%	41.9%	16.2%	46.5%	36.6%	47.5%
Leptynite	7	75.01	0.20	13.67	1.30	0.71	0.61	1.26	3.61	3.48
s.d.		4.2%	45%	11.0%	64.3%	53.7%	50.8%	75.4%	18.0%	39.1%
Granite	7	73.02	0.22	14.91	1.15	0.5	0.74	0.79	3.20	5.67
s.d.		4.1%	100%	6.6%	89.2%	120%	110%	64.6%	28.7%	24.3%
Melts (E)	24	66.50	0.74	16.57	3.28	0.4	1.09	0.26	0.32	10.98
s.d.		3.8%	12.2%	5.6%	50.9%	71.4%	100%	34.6%	3.1%	16.1%

N = number of different localities < N analyses; s.d. = standard deviation % of mean value.

References: 1) Lambert, P., 1977, in Impact and Explosion Cratering, Roddy, D.J., Pepin, R.Q., Merrill, R.B., p. 449-460. 2) Janssens, M.J., Hertogen, J., Takahashi, H., Anders, E., Lambert, P., 1977, J. Geophys. Res., 82, 5, p. 750-758. 3) Palme, H., Rammensee, W., Reimold, U., 1980, Abstracts XI Lunar and Planet. Inst., Houston, V. 2, p. 848-850. 4) Lambert, P., 1975, Meteoritics, 70, 4, p. 433-436. 5) Lambert, P., 1976, 4eme R.A.S.T., Paris, p. 248 (abst.). 6) Kraut, F., French, B.M., 1971, J. Geophys. Res., v. 76, p. 5407-5413. 7) Lambert, P., 1977, Earth Planet Sci. Letters, 35, p. 258-268. 8) Lambert, P., 1977, Ph.D. dissertation, Université Paris-Orsay, 515 p. 9) Lambert, P., this volume.

ROCHECHOUART: GEOLOGY. P. Lambert, Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287

Rochechouart structure (France: 45°50'N; 000°56'E) affects granitico-gneissic rocks of the NW edge of the French Massif Central. Impact origin was first suggested by (1) and confirmed by (2). No morphologic evidence of the crater has been preserved. The present ground level is exactly tangent to the crater floor. Allochthonous breccias and shock metamorphism in minerals of the target rocks occur in a 12-13 km diameter central zone (3). Fracturation and autochthonous brecciation is still noticeable 10 km away from the center (3). A 135 m drilling emplaced directly in the basement 8 km S of the center cross cut about 20 breccia dikes (4). The probable impact point determined from shock zoning study (3) corresponds approximately to the geometrical center of the breccia formation. K/Ar measurements (2, 5-6), paleomagnetism data (7) and fission tracks study (8) give a Triassic/Jurassic age for the Rochechouart impact event. In the central zone the allochthonous breccia unit is less than 12 m thick (average) and ranges from 0 to 60 m thick. The formation is thinner and discontinuous at the periphery. Total volume of the allochthonous breccia formation is about 0.45 km³. The volume of melted material is less than 0.06 km³ with an almost equal contribution from suevite-like and impact melt breccias. Glass-free mixed breccias are the most abundant representing about half of the volume of the breccia unit. Readjustment of the Rochechouart cavity is inferred from shatter cone orientation, paleomagnetism data and from morphological considerations. The crater floor limit is thoroughly exposed within the 100 km² central zone. Unlike currently known complex impact craters which all display central peak or ring and/or external annular depression, Rochechouart is characterized by a remarkably flat floored cavity. The elevation of the crater floor limit ranges from 160 to 300 m and in most cases is comprised between 200-250 m. Although Rochechouart provides a unique opportunity to study the nature and texture of materials on both sides of the cavity limit, (precious informations for investigating excavation and readjustment mechanism of complex crater), field observations are confusing. Each type of breccia may locally be observed at the bottom of the crater. Significant changes in the nature of the breccia may occur within 10 to 100 m in any direction. There is apparently no clear stratigraphic relationship between the different breccias. The bad quality of outcrops allied to the extreme thinness of the breccia largely limit such a stratigraphic study. Series of shallow drillings (2 to 50 m deep) would be considerable help.

On top of the suevite-like breccia at Chassenon a stratified ash formation bearing shock metamorphosed minerals (3) has no equivalent among other impact structures. It may represent the last deposits associated with the crater formation. It is a flat lying and non deformed layered unit indicating deposition after the end of the readjustment of the cavity. The 10 cm transitional zone at the base of the formation indicate a slight overlapping between the end of movements affecting the suevite and the beginning of the fine debris fall. The original thickness of the ejecta formation at this place--3.5 km N of the center--would be only about 60 m.

References: (1) F. Kraut, 1968, C.R. Academie des Sciences de Paris, Tome 264; (2) F. Kraut, B.M. French, 1971, J. Geophys. Res., 76, p. 5407-5413; (3) P. Lambert, 1977, Earth Planet. Sci. Letters, 35, 258-268; (4) P. Lambert, 1981, Proc. Lunar Planet. Sci. Conf. 12, in press; (5) P. Lambert, 1974, These doctorat 3eme cycle, Université Paris XI; (6) P. Lambert, 1977, These de doctorat d'état, Université de Paris sud Orsay; (7) J. Pohl and H. Soffel, 1971, Zeitschrift fur Geophysik, 37, 857-866; (8) G.A. Wagner, D. Storzer, 1975, Meteoritics, 10, 4, 503-504.

COMPARATIVE MORPHOLOGY, PALEOECOLOGY AND PALEOBIOGEOGRAPHY OF MASSIVE EXTINCTIONS AND EVOLUTIONARY RADIATIONS IN MARINE PLANKTON, Jere H. Lipps, Dept. of Geology, Univ. of California, Davis, Ca. 95616.

At times of massive extinctions (mid-Cretaceous, Cretaceous-Tertiary boundary and Eocene-Oligocene boundary), the morphologic, paleoecologic and paleobiogeographic relationships changed in a similar, systematic and repeated fashion. The periods of extinction were selective, not all species becoming extinct. Those that remained were always those with simple morphologies, they were biogeographically widely distributed, and they did not segregate vertically in the water column during life. At times of evolutionary radiations, species diversity was high, and included species with complex and specialized morphologies that were distributed in restricted provinces and that segregated vertically at least during part of their lives. These observations place constraints on the physical event or events that may have occurred at times of extinctions.

Prior to extinction events, morphologies of plankton were overall much more complex. Many species in most groups had special features, like spines, keels, apertural modifications, differentiated plates, structural supports and thickened skeletons. These complex species became extinct whereas species with simple morphologies remained. In some groups of living plankton (foraminifera and coccolithophorids, for examples), complex and specialized morphologies occur in species known to segregate vertically in the water column at some time in their life cycles. Species with simple morphologies today do not appear to segregate, and they live in vertically unstructured water masses.

Paleobiogeography of plankton during periods of radiation shows provinciality related to inferred water mass distributions. During and following periods of massive extinctions, paleobiogeography shows widespread, cosmopolitan biotas.

These observations and inferences suggest that massive extinctions occurred when oceans were more homogeneous in their vertical and horizontal water mass structure. Today, water structure is related in large part to thermal gradients implying that the oceans during extinctions were thermally more uniform. Indeed, oxygen isotopic data show that the thermal gradients were low during extinctions and that they increased during evolutionary radiations. Organisms that indicate increased ocean productivity also became extinct during massive extinctions, suggesting that the homogeneity of the oceans was not due to increased vertical mixing, which would have brought nutrients into the euphotic zones and thus increased productivity. Instead, oceanic circulation appears to have become sluggish.

The evidence from fossil pelagic organisms thus indicates that the mechanism responsible for extinctions operated probably through thermally-linked changes in the vertical and horizontal water mass structure. An extraterrestrial large-body impact either into the ocean or onto land could not by itself produce these conditions, or the selective extinction of vertical segregators, the simultaneous extinction of species requiring eutrophication, and the cosmopolitan paleobiogeographies. Such an impact would necessarily be required to change oceanographic conditions world-wide, and for several millions or tens of millions of years. Although plankton paleobiology does not eliminate the hypothesis of a large-body impact, it does require that secondary effects be postulated that would cause the patterns observed.

MORE DEFINITIVE STRATEGIES TO ASSESS LIKELY ECOLOGIC EFFECTS OF
LARGE BODY IMPACTS ON MARINE LIFE; H. A. Lowenstam, Div. of Geol. & Planet.
Sci., Caltech, Pasadena, CA 91125

A pronounced temperature rise and dust clouds, in excess of those produced by major volcanic eruptions have been advocated as some of the major effects by large body impacts on the biosphere. A temperature rise of 10°C and even higher is postulated by some investigators to account for episodes of mass extinction in the Phanerozoic. This is in the process of being checked via $\delta^{18}\text{O}$ determined temperatures from plankton skeletal carbonates. It can be assessed by inference, also, via data on maximum temperature tolerances obtained on marine benthic and nektonic animals in the laboratory. These data compiled by Emiliani et al. (1981) for higher taxa which survived the Cretaceous-Tertiary boundary in the sea suggest that the temperature rise at this time interval was more likely between 8°C and 10°C . There are recent shallow water habitats with seasonal maximum temperatures of between 10°C to 14°C in excess of mean ocean water temperatures that have reef building communities (Kinsman, 1964). Similar fossil occurrences, preceding in time large body impacts should single out by their absence those groups of organisms which could not tolerate temperatures attained in consequence of major body impacts, hence become extinct, whereas those which survived the temperature rise should be represented. More extensive data are needed on predator-prey relations in the fossil record, particularly for predators with highly specialized food requirements, to distinguish organisms, eliminated by temperature elevation from those as a consequence deprived of their food sources. We have some data from our experimental studies to show that a temporary major temperature rise can be beneficial to some organisms by triggering excessive growth or mass reproduction resulting in takeover of habitats at the exclusion of other species.

Other aspects to be considered concern the role of free amino acids, body remains and in particular of bacteria as potential food sources for filter- and deposit-feeders as well as scavengers. This seems necessary at least for the Cretaceous-Tertiary boundary event, where there is clear documentation for significant decimation of the standing crop and diversity of primary producers. If this phenomenon is, as postulated, due to effective atmospheric shielding by disintegration products of an extraterrestrial body, an explanation is required why far less photosynthesis impediment is in evidence on land.

TESTS OF A PROPOSED EXTRATERRESTRIAL CAUSE FOR THE FRASNIAN-FAMMENIAN (LATE DEVONIAN) EXTINCTION EVENT. G.R. McGhee, Jr., Department of Geology, Field Museum of Natural History, Chicago, IL 60605 and Department of Geological Sciences, Rutgers University, New Brunswick, NJ 08903; R. Ganapathy, Research Laboratory, J.T. Baker Chemical Co., Phillipsburg, NJ 08865; and E.J. Olsen, Department of Geology, Field Museum of Natural History, Chicago, IL 60605

One way of testing the recently proposed connection between asteroid impacts and major biotic extinctions would be to search for the geochemical signature of such an impact in association with major extinction events other than the Cretaceous-Tertiary event. With this potential test in mind we have sampled and are currently analyzing strata in New York State spanning the Frasnian-Famennian boundary, a period of time in the Late Devonian which saw the third largest extinction event in the past 500×10^6 years. Interestingly, it was suggested over a decade ago (1) that the Frasnian-Famennian extinctions may have been caused by the impact of a large meteorite.

The most extensive exposures of Late Devonian strata in North America occur in central and western New York State. In New York, the Frasnian-Famennian boundary has traditionally been placed at the boundary between the Java Group and the Canadaway. Highest occurrences of ammonoids of the Manticoceras Stufe (=Frasnian Age) occur in the Hanover Gray Shale member of the Java Group, while lowest occurrences of conodonts of the Upper Palmatolepis triangularis Zone (=Famennian Age) occur in the overlying Dunkirk Black Shale of the Canadaway, and the upper part of the underlying Hanover.

Three field localities were chosen for stratigraphic sampling:

Locality	7.5' Quadrangle	Latitude	Longitude	Paleoenvironment
Dunkirk Beach	Dunkirk	42°29'30"	79°21'05"	Deep Basin
Walnut Creek Gorge	Silver Creek	42°31'00"	79°10'20"	Deep Basin
Mills Mills	Portageville	42°30'05"	78°07'15"	Delta Slope

These sections were selected to provide variation in paleoenvironment and sedimentary facies. The Dunkirk Beach and Walnut Creek Gorge field areas were located in deep water, basin axis regions of the Appalachian Sea during the Late Devonian. Sediments at the Mills Mills section were deposited in shallower water delta slope regions, and the Hanover Gray Shale interfingers here with the Wiscoy Sandstone member of the Java Group. As the contact between the Dunkirk Black Shale and the Hanover Gray Shale is gradational, samples were collected for a distance of 1 to 2 m above and below the interfingering zone of contact. Shale specimens were taken in 2 cm intervals at the Dunkirk Beach and Walnut Creek Gorge localities, and in 4 cm intervals at the Mills Mills locality, located 102 km east of the Dunkirk Beach site.

Neutron activation analyses of the shale samples, in search for the enrichment of meteoritic materials within these stratigraphic sections, is currently in progress. Preliminary results in the Walnut Creek Gorge samples are anticipated by October 1981.

(1) McLaren, D.J. (1970) Jour. Paleontology, v. 44, p. 801-815.

VERIFIED IMPACT STRUCTURES IN BRAZIL

John F. McHone, Jr., Department of Geology, Arizona State University,
Tempe, Arizona 85287

Several photocircular features visible on satellite and aviation images of Brazil have been proposed in the literature as *possible* impact structures (1-4). Three of them, Araguainha, Serra da Cangalha, and the Riachao Ring, contain shock metamorphosed rocks and are now considered *probable* impact structures. All three features are complex craters with central uplifts. Centripetal movements of the inner rock units are evidenced by thickened, tightly folded and uplifted, outward dipping beds. All are surrounded by flat-lying clastic strata near the margins of intracratonic sedimentary basins where they have been preserved by burial and are presently being revealed by stream erosion.

Araguainha, Mato Grosso (40 km dia, 07°43'S, 046°39'W) lies in the northern Parana Basin and is composed predominantly of Paleozoic sandstones. Brecciated Precambrian basement is incorporated in the central uplift. Quartz grains from the inner Devonian sandstones contain abundant fractures and microscopic optical planar features (5) diagnostic of meteorite impact. Serra da Cangalha, Goias (12 km dia, 08°05'S, 046°52'W) affects Paleozoic sediments in the southeastern Maranhao (also called Paranaiba) Basin. Mississippian quartzite boulders from the base of an inner mountain ring contain shatter cones (3) diagnostic of an impact event and possible planar features visible with SEM (Fig 1). Soft Devonian shales in the central bowl are now 400 m above their regional stratigraphic position but may have lost another 300 m of elevation to removal by erosion. The Riachao Ring in Maranhao (4 km dia, 07°43'S, 046°39'W) lies 40 km to the north in slightly younger Paleozoic and Mesozoic rocks of the same sedimentary basin. Sands weathered from Triassic sandstones form an elevated ring around an uplifted central peak of Permian sandstones. An outward dipping collar of polymict breccia occurs around the periphery of the structure and acts as an erosion resistant shield. Breccia clasts derived from underlying Triassic and Permian formations contain occasional quartz grains with multiple sets of optical planar elements, some of which are parallel to the shock-indicating crystallographic planes $\pi(101\bar{2})$ and $\omega(101\bar{3})$.

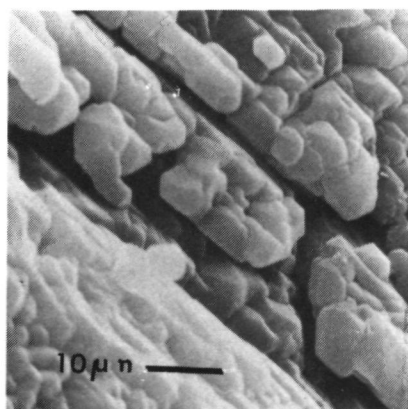


FIG. 1. Planar features in shatter-coned quartzite at Serra da Cangalha, Brazil.

REFERENCES

- 1) Dietz, R.S., and McHone, J. (1974) Impact structures from ERTS imagery, *Meteoritics* v.9, n.4, p.329-333.
- 2) McHone, J.F., Jr. and Dietz, R.S. (1977) Astroblemes in Brazil, *Geol. Soc. Amer., Cordil. Sect. Mtg., Prog. w. Abstr.*, p.116
- 3) McHone, J.F., Jr. (1979) Riachao Ring, Brazil: a new impact site discovered by manned spacecraft, *Apollo Soyuz Test Project, Sum. Sci. Rept.*, v.II, NASA SP412, p. 193-202.
- 4) Beatty, J.K. (1980) Crater Hunting in Brazil *Sky and Telescope*, v.59, p.464-467.
- 5) Dietz, R.S., and French, B.M. (1973) Two possible astroblemes in Brazil, *Nature*, v. 244, p.561-562.

TIN BIDER MULTI-RING IMPACT STRUCTURE (ALGERIA). J.F. McHone*, P. Lambert**, R.S. Dietz*, and M. Houfani***. * Dept. of Geology, Arizona State University, Tempe, AZ 85287; ** Center for Meteorite Studies, Arizona State University, Tempe, AZ 85287; *** SONAREM, El Harrach, Algiers, Algeria.

Tin Bider (27°36'N, 005°07'E) is perched on a southern protuberance of the Tin Rhert Plateau in the Algerian Sahara. The structure, composed of perfectly concentric annular ridges, affects a series of flat-lying Upper Cretaceous argillaceous limestones. The central zone, a 2 km diameter anticlinal dome (A_1) is a vertical core of massive sandstone ringed by two concentric ridges of Upper Cretaceous limestone. The sandstone is brecciated and quartz grains exhibit shock-induced planar elements (1). It is a Lower Cretaceous unit which has been uplifted at least 480 m above its regional stratigraphic position. Surrounding A_1 is a circular synclinal depression (S_1) about 1.5 km wide which is in turn surrounded by another sharp ring anticline (A_2). This second anticlinal ring is truncated by erosion in the SW portion of the structure. Beyond A_2 is a poorly defined syncline (S_2) and finally another circular anticline (A_3) at about 6 km diameter, truncated by the edge of the plateau and still visible only in the NW. The outermost influence of the structure is detectable 4-5 km from the center in the plain surrounding the plateau. Here Senonian clay-and-gypsum bearing formations with a regional dip of about 1° northward begin to tilt progressively 2°-3° inward, forming an outermost ring syncline (S_3). The formation maintains a moderate dip in A_3 and in the outer part of S_2 . In S_2 and A_2 the geometry of exposed beds abruptly becomes very complex. The boundary between deformed and non-deformed zones is well exposed in the cliffs at the edges of the plateau. The well marked contact is remarkably constant and flat, dipping less than 10° inward. The deformed zone begins with intense deformations, over-thrusting and under-thrusting, centrifugal folding, and radial shortening. Nearly vertical and often crenulated "pie crust" strata are very common in the area of A_2 and S_1 . Plastic deformation is still prominent, dominated by ductile deformation. Clay intercalations are intensely folded as well as the limestones which exhibit remarkable meter-scale flat folds, often disharmonically underlain by long chert lenses which also display ductile folding.

No shatter cones, intense fracturing, breccia veins, or breccia lenses were observed in Tin Bider. In the field the only significant evidence of fracturing (or more accurately, failure) are overthrusts in the S_2 - A_2 regions with horizontal amplitudes which can reach about one half km.

A more detailed description of the geology and impact origin of Tin Bider is presented separately in (1).

References:

- (1) Lambert, P., McHone, J.F., Jr., Dietz, R.S., Briedj, M., Djender, M. (1981) Impact and impact-like structures in Algeria, Part II--Multiringed structures. Meteoritics, Vol. 15, No. 3, in press.

FORMATION OF NOCTILUCENT CLOUDS BY AN EXTRATERRESTRIAL IMPACT; C.P. McKay and G.E. Thomas, Dept. of Astro-Geophysics and The Laboratory for Atmospheric and Space Physics, Univ. of Colorado, Boulder, CO 80309

The impact of a large body in the oceans would inject large quantities of water through the tropopause cold trap into the stratosphere and lower mesosphere. We consider the consequences of enhanced water vapor densities on the middle atmosphere (50-100 km) chemistry and heat budget.

The increased mixing ratio of hydrogen dramatically decreases the ozone concentration above 50 km. Catalytic reactions with odd hydrogen are the main sink of ozone in this region. The ozone reduction as well as enhanced water vapor cooling causes a lowering of the average height of the mesopause, as well as a lowering of the average temperature. The lower colder mesopause and the creation of saturation conditions over much of the upper mesosphere would have resulted in a permanent layer of mesospheric ice clouds of nearly world-wide extent. (At present, these exist only at high latitudes and are observed in summer as "noctilucent clouds".)

The globally-averaged albedo resulting from these clouds is dependent on the particulate size and shape, and can be as high as several percent, preferentially covering the summer hemisphere. This could have important implications for the short-term climate following a large-body impact.

IMPACT INTO THE EARTH'S OCEAN FLOOR DURING THE LAST BILLION YEARS: PRELIMINARY EXPERIMENTS, THEORETICAL MODELS, AND POSSIBILITIES FOR GEOLOGICAL DETECTION. William B. McKinnon, Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721 and P. Goetz, Department of Earth and Space Sciences, SUNY Stony Brook, Stony Brook, NY 11794.

In the last billion years it is estimated that 50 ± 20 Copernican-sized craters (diameters ≥ 100 km) have formed in the ocean floor. If a 5-km depth crater in a water half-space is taken as the threshold for significant interaction with the sea floor, more than 50,000 such events have occurred in the same length of time (1,2,3). While none have been identified to date, impact processes and plate tectonics are sufficiently understood to rectify this.

Impact Experiments- We have performed a preliminary set of experiments, using standard 22 caliber ammunition and dense saturated sand as a target medium. Long Island quartz beach sand was overlain by a 0.5 cm marker horizon of garnet-magnetite beach sand. Water table depth was the only variable. Results for the three experiments are given in the table below. All craters produced were bowl-shaped. The first shot produced widespread ejecta, an uplifted rim, and classic inverted stratigraphy in the sand clots typical of saturated events (4). The cratering efficiency, π_v , and gravity-scaled size (see 3) indicate that this crater formed at the transition from cohesion to gravity domination (5). The second event produced a much steeper ejecta plume, with quartz and g-m sand mixed with the water. This became a sediment load which settled as sorted debris in and about the crater. π_v was noticeably smaller, contrary to expectation. The third shot formed a relatively wide crater with a gentle rim uplift. No sand was observed in the water that hit the witness plate. A spectacular water central peak formed, and the cratered area was thinly blanketed with 1-2mm of sorted quartz sand. Surprisingly, the garnet-magnetite layer was found intact upon sectioning. This was a crater of displacement, not excavation. The qtz blanket was apparently derived from contamination of the g-m layer. Both #2 and #3 had nearly the same final depth. We suggest that this is not coincidental but represents a stability limit (6,7). In this case π_v will be underestimated. While crude and not hypervelocity (381 m/s), the experiments exhibit phenomenology we expect in actual craters in the ocean floor: steep, mixed ejecta plume, gravitational adjustment of the crater to form a shallow basin, and extensive reworking of ejecta and rim and floor materials by violent collapse of the transient water cavity.

Theoretical Models- Topographic amplitude following collapse of the transient crater is less than 1 km. Thus 100-km craters are transiently ≤ 50 -60 km across. For such craters, excavation into the mantle is predicted although asthenospheric influence on outer ring formation (8,9) or uplift-induced volcanism (10) is not. A finite element study of the long-term deformation of the thinned and weakened elastic lithosphere is in progress.

Detection is possible using gravity, topographic, magnetic, seismic, and drill data. In addition, fracture-induced porosity and long-lived, deep hydrothermal activity (11) may make these structures too buoyant to subduct, leading to their accretion at active continental margins (12).

Crater Data Summary

Shot	Water Table Level ^a , cm	Depth ^a , cm	Diameter cm	π_v ^b
1	-2.8	4.3	10.4	190
2	+1.3	1.8	9.0	100 ^c
3	+3.8	2.0	12.0	230 ^c

^aWith respect to pre-impact target surface

^b π_v = mass ratio of crater to projectile, $\pm 10\%$

^cCrater volume extrapolated through water layer

References

- (1) Shoemaker E.M. (1977) In *Impact and Explosion Cratering*, p. 617-628.
- (2) Grieve R.A.F. and Dence M.R. (1979) *Icarus* 38, p. 230-242.
- (3) Schmidt R.M. (1980) *Proc. Lunar Planet. Sci. Conf.* 11th, p. 2099-2128.
- (4) Piekutowski A.J. (1977) In *Impact and Explosion Cratering*, p. 67-102.
- (5) Schmidt R.M. and Holsapple K.A. (1979) *DNA Report 49992*.
- (6) McKinnon W.B. (1980) Ph.D. Thesis, Caltech.
- (7) Melosh H.J. (1982) *J. Geophys. Res.* 87, in press.
- (8) Melosh H.J. and McKinnon W.B. (1978) *Geophys. Res. Lett.* 5, p. 985-988.
- (9) McKinnon W.B. (1981) *Proc. Conf. Multi-ring Basins*, in press.
- (10) Green D.H. (1972) *Earth Planet. Sci. Lett.* 15, p. 263-270.
- (11) Newsom H.E. (1980) *Icarus* 44, p. 206-216.
- (12) Ben-Avraham Z., Nur A., Jones D. and Cox A. (1981) *Science* 213, p. 47-54.

FRASNIAN-FAMENNIAN EXTINCTIONS

Digby J. McLaren, Dept. of Geology, Ottawa Univ., Ottawa, Canada K1N 6N5

A major change in life in the middle of the Upper Devonian has been known locally for some time. Twelve years ago, I suggested that it was recognizable on a worldwide scale, and took place sufficiently rapidly to warrant the term catastrophic. The extinction represented disappearance of animals on a colossal scale. Affected were those that lived on a sublittoral sand or mud bottom or on or around reefs. Major groups included corals and stromatoporoids, both of which virtually disappeared, Orders and Superfamilies of brachiopods and trilobites and other groups. The disappearance took place at a time of almost maximum marine transgression with widespread development of reefs and organic limestones, all of which ended abruptly. Reefs subsequently remained extremely rare until Viséan time. Plants and planktonic and nektonic forms were largely unaffected. Fresh water or muddy water would prove fatal to the types of organisms that disappeared and mud was the favoured hypothesis. It was further suggested that turbulence caused by tidal waves following an oceanic impact of a large extraterrestrial body could have been the triggering mechanism. Subsequent discussions on the extinctions have identified five hypotheses. (1) The Late Devonian was a time of maximum marine transgression and saw extinction of many groups of organisms beginning in the Givetian and culminating in the Famennian; thus the Frasnian-Famennian extinction might merely be an artifact of plotting range-limits on charts. Nevertheless, the extinction in terms of dominant animal species at the close of the Frasnian looks real. (2) Regression followed by transgression was sufficient to extinguish stressed faunas in the epi-continental seas of the world; this might or might not be combined with other factors. Numerous stratigraphic sections, however, appear to be continuous across the Frasnian-Famennian boundary, particularly in off-reef shallow basins in, for instance, Alberta and northwestern Australia. (3) Some form of a global drowning event led to extinction of reefs and associated faunas. But the extinctions may still need some triggering mechanism apart from a rise in sea-level. (4) In South America, faunas in a cold water clastic sediment environment were unaffected. A change in oceanic circulation possibly due to plate movements may have caused cooling throughout the world, and thus extinction of stenothermal organisms. But early Famennian deposits do not suggest cold water; sponge and algal reefs are known in the basal Famennian in Australia and pelletoid carbonates are widespread. (5) The massive extinction was in fact a sudden catastrophe. The possibility of an astronomical cause must still be examined. Both (4) and (5) may prove amenable to testing by chemical or physical means today.

McLaren, D.J. 1970 *Journal of Paleontology* 44, pages 801-815.

DIACHRONEITY OF THE K-T CONTACT AND OF THE DINOSAURIAN EXTINCTIONS.
 Dewey M. McLean, Department of Geological Sciences, Virginia Polytechnic
 Institute and State University, Blacksburg, VA 24061.

Time-rock relationships of the Cretaceous-Tertiary (K-T) "contact" in the Rocky Mountain region indicate that the K-T contact and the last occurrences of the dinosaurs are diachronous and that catastrophe-type extinction theories have no demonstrable foundation. The K-T contact, picked on the basis of pollen changes just above the stratigraphically highest dinosaurian remains, and cited as being isochronous from Alberta, the Dakotas, Montana, and Wyoming, into Colorado, is stratigraphically lower than Brown's "first persistent lignite" K-T contact. Because dinosaurs seemingly disappeared just below the K-T contact creates the illusion of simultaneous terminal Cretaceous extinctions. However, outcrop study areas are parts of time transgressive lithostratigraphic units deposited as eastward prograding delta systems during the last Cretaceous (R4) marine regression of the Western Interior Cretaceous Seaway; units deposited are the marine prodelta Pierre and delta front Fox Hills formations, and the latest Maestrichtian continental delta plain Lance-Hell Creek formations that contain the final record of the dinosaurs. Along the eastward migrating strandline occurred swamps that produced the continental Cretaceous and Tertiary coals, including Brown's K-T contact lignite; coals forming in migrating swamps are, by necessity, time transgressive. Thus, the K-T contact whether picked by pollen, whose distribution is controlled in part by migrating delta plain environmental conditions, or Brown's lignite, is diachronous, as are the last dinosaur remains. In Colorado, the K-T contact (pollen) is 24-35 m below radiometric dates of 65.9 and 66.4 m.y.; at Hell Creek, Montana, where the pollen change coincides with Brown's lignite the K-T contact is 61.7 to 62 m.y.; in Alberta, the K-T (pollen) is about 63 m.y. Hiatuses at the K-T contact due to Laramide uplift are widespread in the Rocky Mountain region. Claims of simultaneity of marine and continental extinctions based on attempts to correlate the marine K-T contact at Gubbio, Italy, with the continental K-T contact in the San Juan Basin, New Mexico, via magnetostratigraphy are weakened by knowledge of the diachronous continental K-T contact, as are attempts to relate enhanced levels of iridium at the K-T contact with asteroid impact. An "iridium clay" chronohorizon due to asteroid impact would cut across Cretaceous and Tertiary time transgressive boundary strata, and would occur at the K-T contact only where intersecting it, and otherwise only fortuitously. The basal Tertiary "iridium clay" in marine strata does not seem to rest upon latest Maestrichtian strata. At Stevns Klint, Denmark, it (fish clay) rests upon a Cretaceous unconformity ubiquitous in Denmark (a K-T transition shallow marine CaCO_3 dissolution, or clay, event is seemingly universal); montmorillonite in the fish clay suggests volcanic origin. Deccan flood basalt volcanism in India linked to India's drift over the Reunion hotspot (65-60 m.y.) was synchronous with the K-T transition extinctions and the iridium event. Volcanic exhalations (via fluctuation of the carbon cycle) account for the K-T transition: drop in $\delta^{13}\text{C}$ values (volcanic CO_2 and reduced carbon have negative values), drop in $\delta^{18}\text{O}$ values (warming, via "greenhouse" conditions), marine CaCO_3 dissolution and clay events (acid gases would lower pH, holding CaCO_3 in solution, allowing a clay layer to accumulate on the Cretaceous unconformity), marine calcareous microplankton extinctions via the CaCO_3 dissolution event, and the dinosaurian extinctions via heat-infertility linkage. Extinctions likely spanned 10^5 - 10^6 years. Origin of the Deccan magmas near the core, where siderophiles exist in cosmical proportions, accounts for the iridium event via mantle plume, or diapir, activity. Neodymium ratios in continental flood basalts indicate lower mantle origin.

THE MECHANICS OF LARGE METEOROID IMPACTS IN THE EARTH'S OCEANS, H. J. Melosh,
SUNY Stony Brook, Stony Brook, N. Y. 11794

Alvarez et al (1) suggest that a meteoroid several km in diameter impacted the earth at the end of the Cretaceous period, initiating the extinctions which define the Cretaceous-Tertiary boundary. Since there is no evidence of a crater of the appropriate size and age on land, it is presumed that the putative impact occurred in an ocean.

When a large meteoroid impacts the ocean, the initial stages of shock compression and energy deposition occur in water. Plane shock wave estimates indicate that pressures range between 3 and 6 Mbar for impact velocities 20-30 km/sec. The shock wave expands, engulfs more water, then eventually reaches the sea floor. A rarefaction closely follows the propagating shock. Since 0.1 Mbar shock compression is sufficient to vaporize water (2) upon release, a large volume of water (1 to 5 times the meteoroid volume) may flash into superheated steam following the rarefaction. The meteoroid debris, lying on top of this steam bubble, is accelerated into the upper atmosphere as the steam "fireball" expands adiabatically.

The crater formed on the seafloor may differ greatly from a "land" type impact because of the initial stage of shock coupling through water. The effective "depth of burst" of the impactor is smaller than it would be on land. In particular, little ejecta from the seafloor may reach the upper atmosphere.

The importance of these effects depends upon the size of the impactor. At the present time, too little is known about the mechanics of a water impact to accurately predict the meteoroid size at which the transition from a steam explosion type of event grades into a hard rock type event. The size is probably in the range of one to perhaps ten km; it is thus important to consider the effects of the ocean in detail when discussing the Alvarez et al hypothesis. In the case of a steam explosion event the material which reaches the upper atmosphere is primarily water (which rapidly condenses to ice as it expands under low pressure conditions) mixed with debris from the impacting meteoroid. The thick stratospheric cloud of ice crystals resulting from this kind of event may allow more light to pass through it than a pure dust cloud, and could have very different climatic effects.

References

- (1) Alvarez, L. W. et al, Science 208, 1095-1108 (1980)
- (2) Kieffer, S. N. and C. H. Simonds, Rev. Geophys. Space Phys. 18, 143-181 (1980).

"RESPONSE TIMES OF PELAGIC MARINE ECOSYSTEMS FOLLOWING A GLOBAL BLACKOUT". David H. Milne, Evergreen State College, Olympia, WA 98505, and Chris McKay, Dept. of Astrogeophysics, University of Colorado.

Analysis of modern marine food chains suggests the time scale and severity of an atmospheric darkening needed to cause them to collapse. A global blackout (reducing sunlight by a factor 10^{-7} , enduring for several years and initiated by an asteroid impact) has been suggested by Alvarez et al (1) as a cause of the widespread extinctions occurring at the end of the Cretaceous period.

Modern pelagic marine food chains consist of 5 trophic levels (2; phyto-and zoo-plankton, small and large fish, top predators). Phytoplankters cease reproduction at depths where sunlight is 10^{-2} that of surface levels (3); comparable attenuation by airborne dust would precipitate a food chain collapse. Tropical food chains would collapse more rapidly, following onset of a blackout, than would those of higher latitudes. Tropical zooplankton may outweigh phytoplankton and grazing rates are typically sufficient to eliminate all plants within a few days (3). Metabolic rates are higher in warm waters, life spans are shorter than in cold seas, and neither fish nor zooplankters are adapted to prolonged seasonal food shortages.

Collapse time scales can be estimated from plankton growth models, starvation data and life cycle data. For temperate seas, Riley's (4) model gives 100-300 days for disappearance of the zooplankton (upper limits; summer and fall, respectively). Planktivorous and predatory fish can probably resist starvation for 1-2 months at other times (5,6). Top predators (e.g. sharks) can survive 5 months' starvation (7). Estimates (using daily rations and metabolic rates) give shorter times for tropical seas. A blackout afflicting modern seas would need to persist for one month to initiate food chain collapse in the tropics, at least three months to do so in temperate seas, and would need to end within one year to prevent the total extermination of marine life in tropical waters.

The widespread warm Cretaceous seas would be comparable to the modern tropics. The extinction pattern of final Cretaceous time is compatible with the occurrence of a shorter and less severe blackout than that envisioned by Alvarez et al.

1. Alvarez, L., W. Alvarez, F. Asaro & H. Michael. 1980. Science 208: 1095-1108.
2. Ryther, J. 1969. Science 166: 72-76.
3. Cushing, D. 1975. Marine Ecology & Fisheries. Cambridge U. Press.
4. Riley, G. 1947. Jour. Mar. Res. 6: 104-113.
5. Shulman, G. 1974. Life cycles of Fish. J. Wiley & Sons, N.Y.
6. Love, R. 1970. The Chemical Biology of Fishes. Academic Press, N.Y.
7. Budker, P. 1971. The Life of Sharks. Columbia U. Press, N.Y.

IMPACT MECHANICS OF LARGE BOLIDES INTERACTING WITH THE EARTH AND THEIR IMPLICATION TO EXTINCTION MECHANISMS by John D. O'Keefe and Thomas J. Ahrens, Seismological Laboratory, California Institute of Technology, Pasadena, California 91125.

The extinction that occurred at the Cretaceous-Tertiary boundary (K-T) were both major and diverse. Detailed calculations of the mechanics associated with the impact of both asteroids and comets have been carried out in order to provide a physical basis of the extinction bolide theory. Specific issues examined are: 1) is the extreme enrichment of projectile material (up to 21%) in the K-T layer relative to impact breccias and melts on the moon (<1%) consistent with impact, 2) what is the range of sizes of impactors if the mass of the K-T layer represents ejecta lofted to a height >10km, 3) what is the partitioning of energy in the impact process; how much is transferred to the planet and how much is available to heat the atmosphere and oceans and 4) what is the temporal sequence of impact phenomena that could give rise to the diverse set of extinctions observed?

The impact calculations we have performed were carried out using a two-dimensional finite-difference compressible hydrodynamic numerical technique. The range of impact velocities we considered varied from 5 to 72 km/s and the density of impactors varied from 7.8 (iron), to 2.9 (asteroids), 1.0 (water), to 0.01 g/cm³ (distended comets).

The enrichment of the meteoritical material in the K-T layer relative to lunar impact breccias is explained by calculations which demonstrate that the high speed ejecta lofted to heights >10km in the atmosphere is enriched in projectile material and is consistent with the measured concentrations. This enrichment is independent of bolide density, implying that enrichment can not be used to determine either asteroidal or cometary impact.

Assuming the K-T layers represents impact ejecta lofted to heights >10km we find 10 to 200 bolide masses are lofted into the stratosphere for impact velocities from 7.5 to 45 km/s. For asteroids, the diameter range varied from 8.9 to 3.2 km for impact velocities of 7.5 to 45 km/s. For cometary impactors (density = 0.1 g/cm³), the diameter range varied from 30 to 10 km for impact velocities of 7.5 to 45 km/s.

The partitioning of energy between the planet and atmosphere was computed for both asteroidal and cometary impactors. The important considerations for extinction mechanisms is the fraction of projectile initial kinetic energy that becomes ejected into the atmosphere. That fraction for asteroidal impacts is 0.1 to 0.5 for impact velocities varying from 5 to 45 km/s and for cometary impactors it is 0.8 for impact velocities of 15 km/s.

The temporal sequence of impact phenomena we envision is: upon penetration of the atmosphere by the bolide an insignificant amount of mass and energy is transferred to it. The primary energy transfer occurs upon impact with the planetary surface. The resulting ejecta introduces 10 to 200 times the bolide mass and a significant fraction of the initial kinetic energy (>0.1) into the atmosphere. This energy results in a prompt heating of ~20°C (global average) lasting for ~5 days. The mass ejected to the stratosphere and distributed worldwide would reduce photosynthesis and change the global climate for several years. The passage of high speed ejecta through the atmosphere could produce high temperature shock waves, and thus NO, which could react to deplete the ozone layer for perhaps a decade. The impact into the ocean would exhibit all of the above phenomena including the ejection of large amounts of water into the stratosphere which could perturb the earth's radiative equilibrium and also deplete the ozone layer.

PERMO-TRIASSIC VERTEBRATE EXTINCTIONS; E. C. Olson, Univ. of Calif., Los Angeles, CA 90024

The massive extinction of invertebrate animals during the Late Permian and resurgence of new families during the Triassic is well documented. It appears to be related to sharp reduction in the habitat areas of major groups as shallow sea environments became increasingly reduced. Sharp changes occur as well in terrestrial vertebrates, but the patterns are distinctly different and occur in two phases. The first major decrease in numbers of families occurs at the end of the Lower Permian (the Kungurian-Guadalupian transition). The loss comprises the great majority of families and their immediate derivatives which had persisted from the Coal Measures into the Lower Permian. The second marks the sharp decrease of the reptilian families involved in the therapsid radiation of the Upper Permian. A few "advanced" families persisted, but major replacement by archosaurians took place in the Triassic.

Many of the major groups of reptiles and amphibians (orders and families) can be shown to comprise relatively small animals during their initial stages and to evolve to larger species with time. Subsequent families appear to arise from the smaller, less specialized members of their antecedents. As a rule, thus, when an order or family approaches extinction, it is the larger species that are involved in the event. Successive groups of Permian and Triassic amphibians and reptiles follow this general course. The last of the very mammal-like reptiles, which found survival only in mammals were extremely small. Other therapsids and the ancient amphibian groups that persisted longest during the increase in archosaurs were large. Clearly a relationship of survivorship under rapidly changing conditions and the relative sizes of animals in the affected lines exists. Equally the relationship is extremely complex and initially meaningful only when analyzed for each case. When this has been done significant generalizations may be attainable.

ENERGY COUPLING FOR METEORITIC AND COMETARY IMPACTS.

D.L. Orphal¹, D.J. Roddy², P.H. Schultz³, W.F. Borden¹ and S.A. Larson¹.

¹California Research & Technology, Livermore, CA 94550; ²U.S. Geological Survey, Flagstaff, AZ 86001; ³Lunar and Planetary Institute, Houston, TX 77058.

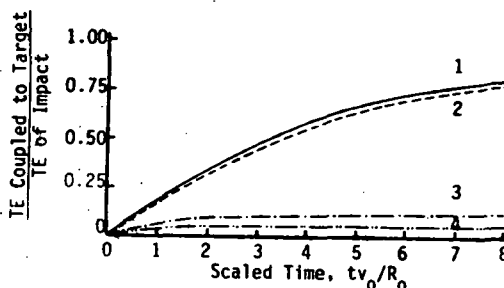
Calculations reveal nearly an order of magnitude difference in the fraction of impact energy coupled to a planetary body by meteoritic and cometary impacts. Meteoritic impact was modeled as impact of a 10^{12} g spherical iron projectile against a gabbroic anorthosite half-space at velocities of 5 km/sec and 15.8 km/sec (1). Cometary impact was modeled as the impact of a porous spherical projectile composed of water (and void) against a limestone half-space at velocities of 5 km/sec and 15 km/sec. The cometary projectile had an initial density of 0.06 g/cc and a radius of 500 m and 250 m for the 5 km/sec and 15 km/sec cases, respectively.* The equation of state used to describe the cometary body included liquid/vapor phase transition and a pore collapse model similar to that used for earth materials. Key impact parameters and the fraction of the impact energy coupled to planetary material are:

Calc. No.	Projectile			Target		Fraction of Impact Energy Coupled To Target
	Matl.	ρ_0 (g/cc)	v_0 (km/sec)	Matl.	ρ_0 (g/cc)	
1	Iron	7.86	5.	Gabbroic Anorthosite	2.9	0.88
2	Iron	7.86	15.8	Gabbroic Anorthosite	2.9	0.86
3	Water	0.06	15.	Limestone	2.7	0.12
4	Water	0.06	5.	Limestone	2.7	0.06

Energy coupled to the planetary body for meteoritic and cometary impact is also shown in the figure where time has been scaled by the ratio of the impact velocity, v_0 , to the radius of the impacting projectile, R_0 . For meteoritic impact nearly 90% of the impact energy is coupled to planetary material, some of which may later escape (2). Increasing the impact velocity from 5 km/sec to 15.8 km/sec has essentially no effect on energy coupling, although the amount of material which will later escape will vary with the impact velocity (2).

In contrast, cometary impacts are calculated to couple only about 10% of the impact energy to planetary material and coupling varies significantly with impact velocity. For the 15 km/sec cometary impact about 12% of the impact energy was coupled to planetary material while for the 5 km/sec impact only about 6% of the energy was coupled.

*The low density is an effective bulk density at impact and may not reflect the density of the projectile prior to atmospheric entry.



- (1) D.L. Orphal, et al. (1980) Proc. Lunar Planet Sci. Conf. 11th, p. 2309-2323.
 (2) J.D. O'Keefe and T.J. Ahrens (1977) Science, p. 1249-1251.

IRIDIUM ABUNDANCE MEASUREMENTS ACROSS THE CRETACEOUS-TERTIARY BOUNDARY IN THE SAN JUAN AND RATON BASINS OF NORTHERN NEW MEXICO. C. J. Orth, J. S. Gilmore, and J. D. Knight, Los Alamos National Laboratory, Los Alamos, NM 87545, C. L. Pillmore and R. H. Tschudy, U. S. Geological Survey, Denver, CO 80225, and J. E. Fassett, U. S. Geological Survey, Albuquerque, NM 87125

We are measuring trace element abundances and searching for anomalously high iridium (Ir) concentrations in sedimentary rocks that span the Cretaceous-Tertiary boundary in the San Juan and Raton Basins of northern New Mexico and southern Colorado. Using neutron activation and radiochemical separations, we have identified a strong Ir anomaly in core samples taken from a site in York Canyon, about 50 km west of Raton, New Mexico. The anomaly occurs in sedimentary rocks laid down under fresh-water swamp conditions, at the base of a thin coal bed, where several Cretaceous pollen species become extinct. At this same level the angiosperm (flowering plant) pollen to fern spore ratio drops abruptly from 30 to 0.1; it recovers to about 10% of its previous value about 18 cm up in the succeeding sediments. At the anomaly the Ir concentration reaches a value of 5×10^{-9} g/g of rock over a background level of about 10^{-11} g/g observed above and below. The Pt/Ir atom ratio in samples at the Ir peak is 3 ± 1 . Other trace elements enriched by a factor of 2 to 3 include Sc, Ti, V, Cr, Mn, Co, and Zn. Mass-spectrometric ^{244}Pu analysis on three samples, two from the Ir peak and one from a presumed "blank" coal bed 11 meters deeper, gave no signal above background, corresponding to $\leq 1.9 \times 10^6$ atoms/g of coal or $^{244}\text{Pu}/\text{Ir} \leq 10^{-7}$ at the peak. In the San Juan Basin we have located a small Ir "spike" (55×10^{-12} g/g over a local background of about 8×10^{-12} g/g) at the base of the upper conglomerate of the Ojo Alamo Sandstone near De-na-zin Wash. This small Ir spike, which is accompanied by high concentrations of Co and Mn, may be due to chemical enrichment in an aquifer.

THE IDENTIFICATION OF PROJECTILES OF LARGE TERRESTRIAL IMPACT CRATERS

H. Palme, Max-Planck-Institut für Chemie, Abtlg. Kosmochemie, 65 Mainz, F.R.G.

WHY? Projectiles of terrestrial impact craters are most likely found among Apollo asteroids. With their eccentric orbit they cross the orbit of the Earth from time to time. Because of their short dynamical life times, they must be ultimately derived from long lived sources, such as main belt asteroids or comets (1). A knowledge of the composition of Apollo asteroids is therefore essential, when considering the question of their origin. Since at least some classes of meteorites may be pieces of Apollo asteroids, their origin may also be relevant for the origin and distribution of meteorites.

Another reason why the composition of projectiles is important, is, that detailed modelling of large impacts on Earth requires the knowledge of the type of projectile (e.g. iron or stony meteorite).

HOW? Since projectiles of large terrestrial craters hit the Earth with undiminished velocity, the energy of the impact is sufficient to completely melt or vaporize the meteorite. However the meteorite may leave its chemical imprint on some of the rocks formed during the impact. Elements with high concentrations in meteorites and low concentrations in the target rocks are the best indicators for the presence of a meteoritic component. These are siderophile elements, e.g. Ir, Os, Ni, Pd, but also Cr. Enrichment of these elements indicates the presence of a meteoritic component. If their relative abundances match the abundance pattern of a certain type of meteorite, the impacting body can be assigned to this type of meteorite. Since the target rocks are not completely free of "meteoritic elements", the contribution of these rocks must be subtracted to obtain the true meteoritic signal. The highest meteoritic contamination is generally found in melt rocks produced during the impact. Impact melts from Clearwater East contain up to nearly 10 % of meteoritic material (2).

RESULTS: There are 78 probable impact structures with diameters <1 km (3). Four of these were almost certainly made by undifferentiated meteorites (chondrites). These are: Clearwater East (2), Lappajärvi (4), Wanapitei (5), and Brent (6). Chondritic projectiles have been suggested for additional two structures: Ries (7) and Rochechouart (8,9). These assignments are not unambiguous (10,11). There is good evidence that several craters were not made by chondrites: Aouelloul (iron or stony iron, 12), Sääksjärvi (stony-iron, 9), Nicholson Lake (achondrite, 5), Gow Lake (iron?, 5), Strangways (achondrite, 13).

In summary, there is good evidence that all major groups of meteorites (chondrites, achondrites, stony-iron meteorites and iron meteorites) are represented among projectile types of terrestrial impact craters.

Literature: 1.) Wetherill G.W. (1976) GCA 40, 1297. 2.) Palme H. et al. (1979) PLPSC 10th, 2465. 3.) Grieve R.A.F. and Robertson P.B. (1979) Icarus 38 212. 4.) Göbel E. et al. (1980) Z. Naturf. 35a 197. 5.) Wolf R. et al. (1980) GCA 44, 1015. 6.) Palme H. et al. (1981) GCA in print. 7.) El Goresy A. and Chao E.C.T. (1976) EPSL 31, 330. 8.) Horn W. and El Goresy A. (1980) Lunar and Planetary Sci.-XI, 468. 9.) Palme H. et al. (1980) Lunar and Planetary Sci.-XI, 848. 10.) Janssens M.-J. et al. (1977) J. Geophys. Res. 82, 750. 11.) Morgan J.W. et al. (1979) GCA 43, 803. 12.) Morgan J.W. et al. (1975) PLPSC 6th, 1609. 13.) Morgan J.W. et al. (1981) Lunar and Planetary Sci.-XII, 714.

CAMBRIAN EXTINCTION EVENTS, Allison R. Palmer, Geological Society of America, Boulder, Colorado 80301.

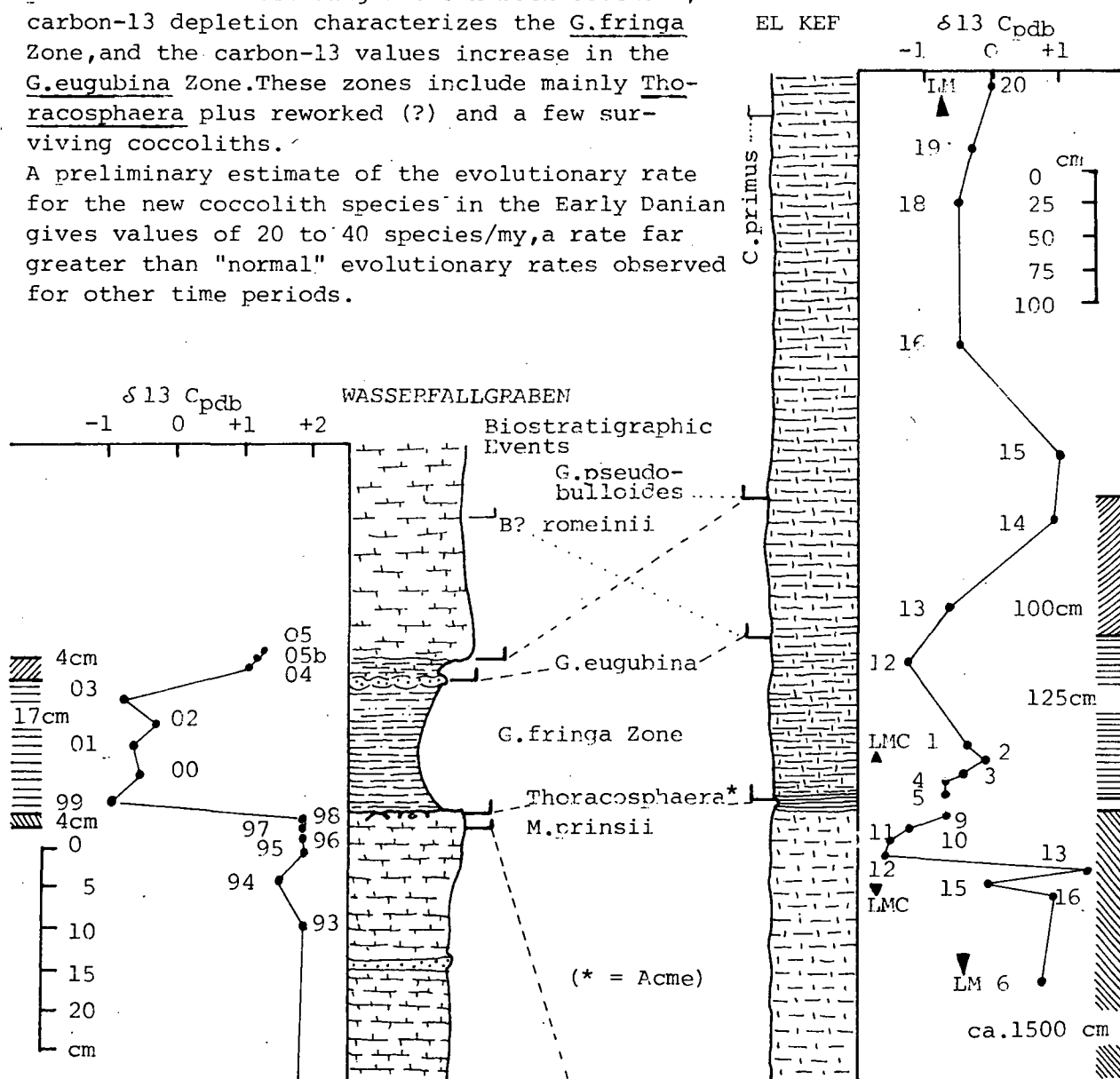
At least three and possibly five times during the Cambrian, at intervals spaced from 5 to 10 million years apart, the shallow shelves of North America and perhaps other Cambrian continents were subjected to an event with almost instantaneous impact that completely and permanently altered the makeup of the trilobite communities that dominated the Cambrian marine environment. Following each event, trilobite assemblages change from low-density high-diversity to high density-low diversity assemblages. Families that dominated the scene for millions of years and experienced normal evolutionary radiation are abruptly terminated. The replacement trilobites following each event seem to represent the same conservative stock and to come from open shelf or more seaward cooler (?) environments. They interact with a few opportunistic survivors of the event for a short but distinct period of time, gradually taking over total dominance of the shallow sea. There is no evidence in the faunal record before each event of any precursor warnings of impending doom. No consistent change in the sedimentary record at either the micro or macro level is noted at or following the extinction event; often the event is recorded within a single bed, and less than 10 centimeters of miogeoclinal limestone separates faunas before and after the event. The best recorded event is at the base of the Late Cambrian Pterocephaliid biomere. Subtle biofacies patterns of trilobite complexes across the shallow seas prior to the event are "frozen" by the event. The record of this event, within tens of centimeters of section, is known from Nevada, Utah, Montana, Wyoming, Arizona, Texas and Tennessee. No cause has yet been identified that is independently verifiable, although the effect is interpreted to be one of sudden cooling of the environment.

PRECISION BIO - AND ISOTOPE-STRATIGRAPHY AND THE "CATASTROPHIC" EXTINCTION
OF CALCAREOUS NANNOPLANKTON AT THE CRETACEOUS/TERTIARY BOUNDARY

Katharina Perch-Nielsen, Qixiang He and Judith McKenzie,
Geology Institute, ETH, 8092-Zürich, Switzerland

A "large body impact" has been proposed, among other theories, as the cause of massive fauna and flora extinctions at the Cretaceous/Tertiary boundary. New data from a nearly complete Cretaceous/Tertiary boundary section at WASSERFALLGRABEN in S. Germany and from the most complete section studied to date at EL KEF, Tunisia are presented. At El Kef, we found a 2-3‰ negative carbon-13 excursion in bulk samples from about 10 cm below the clay layer, which usually represents the base of the Tertiary. This excursion is interpreted as a drastic decrease in surface-water productivity, which is also reflected in the drastic decrease in coccolith abundance from samples LMC 13 to LMC 12; no calcite is preserved in samples LMC 8-6. These intervals are not preserved at Wasserfallgraben. In both sections, carbon-13 depletion characterizes the *G. fringa* Zone, and the carbon-13 values increase in the *G. eugubina* Zone. These zones include mainly *Thoracosphaera* plus reworked (?) and a few surviving coccoliths.

A preliminary estimate of the evolutionary rate for the new coccolith species in the Early Danian gives values of 20 to 40 species/my, a rate far greater than "normal" evolutionary rates observed for other time periods.



SIZE:RANK OF RINGS FOR LARGE IMPACT CRATERS: SYSTEMATIC TRACES IN THE EARTH'S ROCKS. Richard J. Pike, U.S. Geological Survey, Menlo Park, CA 94025.

Large impacts, except perhaps those in deep water or those caused by especially diffuse projectiles, leave evidence in the crust. The scar from an impact large enough to have affected evolution probably is a multiringed basin > 20 km in diameter--with at least three concentric rings or arcs of faults, folds, scarps, fractures, and zones of melted or brecciated rocks--rather than a central-uplift ("complex") crater 3 km to 20 km across or a bowl-shaped ("simple") crater < 3 km across [1,2]. The actual size of the basin, and hence the magnitude of the impact, can be difficult to estimate because topographic and structural geologic evidence for the rings often is faint and fragmentary. A systematic pattern among observed rings described here may help establish basin sizes and reveal additional rings.

Graphs of \log_{10} ring radius versus ring rank (equally spaced) were plotted for 24 basins on Earth and the planets (92 rings). Rank, the relative radial position of a ring in a given basin, is expressed as a Roman numeral starting with I for the smallest possible ring. The resulting graphs are linear, and slope close to $\sqrt{2}$ (average 1.41 ± 0.03), because many adjacent rings (especially in the best-preserved basins) are spaced by increments of $\sqrt{2}$ [3,4,5]. This relation is so common that non- $\sqrt{2}$ spacings also are assumed to follow it: a spacing that deviates strongly from a $\sqrt{2}$ increment probably represents not a fundamentally different spacing rule but rather an apparently missing ring that is either undetected or that potentially could have developed during impact. Thus each apparent gap is assigned a rank corresponding to its radius and $\sqrt{2}$ separations from adjacent rings.

The ranks range from I to VII, although no basin has all seven, but usually three or four. Rings II, IV, V, and VI are present at the Ries; Popigai seems to have rings I through IV. The size:rank model proposed here contains seven rings, in order of decreasing prevalence (frequency, n , out of 92) and (commonly) prominence: the topographic ring (Ring IV, $n = 24$) and the central-peak ring (II, $n = 22$); the intermediate ring (III, $n = 16$) and the first outer arc (V, $n = 13$); the innermost ring (I, $n = 8$) and the second outer arc (VI, $n = 6$); and the third outer arc (VII, $n = 3$). Rings on ice satellites may not fit this scheme.

Calculations of energy of impact, volume of ejecta, size of projectile, and other quantities needed to assess the effects of large impacts on terrestrial evolution should be based on the diameter of Ring IV, because the topographic rim is the basin feature that corresponds most closely to the rim-crest of a smaller simple or complex crater. According to size:rank analysis, the diameters of topographic rims for five terrestrial basins are: Popigai 95 km, Manicouagan 75 km, Clearwater West 32 km, the Ries 24 km, and Haughton 15 km. These basins are comparatively well exposed and the radii of their concentric features fairly easily measured. As older, larger, and more poorly preserved multiringed basins are sought throughout the stratigraphic record, the number of rings and their radii will be commensurately less clear. Even the topographic rim may be difficult to identify. Geologic evidence for all rings, when analyzed collectively by size:rank, may provide enough data to correctly estimate the magnitude of the impact for such cryptic basins, whose formation may have profoundly affected the course of life on Earth.

REFERENCES: [1] Dence, M.R., 1964, *Meteoritics*, v. 2, p. 249-270; [2] Hartmann, W.K., 1972, *Icarus*, v. 17, p. 707-713; [3] Fielder, G., 1963, *Nature*, v. 198, p. 1256-1260; [4] Van Dorn, W.G., 1968, *Nature*, v. 220, p. 1102-1107; [5] Hartmann, W.K., and Wood, C.A., 1971, *The Moon*, v. 3, p. 3-78.

BIOGEOGRAPHIC EXTINCTION: A FEASIBILITY TEST; D.M. Raup, Field Museum
of Natural History, Chicago, Illinois 60605

Destruction of all life in a single geographic region would mean the "worldwide" extinction of those species confined to the affected region. For example, elimination of all life in Australia would cause the extinction of those marsupials endemic to Australia but not those also having populations elsewhere. Could purely regional biotic crises explain the mass extinctions seen in the fossil record? This proposition has been tested, as follows. The geographic distributions of all families of living terrestrial vertebrates and of all genera of two marine groups (corals and echinoids) were digitized and stored on tape. Then, target points were selected at random on the Earth's surface and several lethal radii were specified. For each target point and each lethal radius, a census was made of those animals that would go extinct by virtue of their living only within the lethal areas. Enough runs were made to build a statistical picture of levels of extinction as a function of lethal radius.

The results show that modern biogeography is far more robust than expected. For lethal radii of 5,000 km (one-quarter of the Earth's surface) extinction rates for terrestrial families and for marine genera average only about 2%. For lethal radii of 10,000 km (one hemisphere) these extinction rates increase to about 12%. The latter figure is considerably lower than has been observed for the four or five largest mass extinctions in the Phanerozoic record. Öpik (1973) estimated impact frequencies of large cometary nuclei and asteroids and the lethal areas that would have been produced. Comparison of Öpik's estimates with the results reported here suggest that there have not been enough large impacts to explain the observed mass extinctions by simple biogeographic means. Therefore, a global or near global biotic crisis is required to account for mass extinctions.

Reference: Öpik, E.J., 1973, *Irish Astron. J.*, 11:113-124.

CRATER SIZE FOR LARGE-BODY IMPACT

R. M. Schmidt, Shock Physics Lab, M/S 45-43, The Boeing Co., Seattle WA 98124

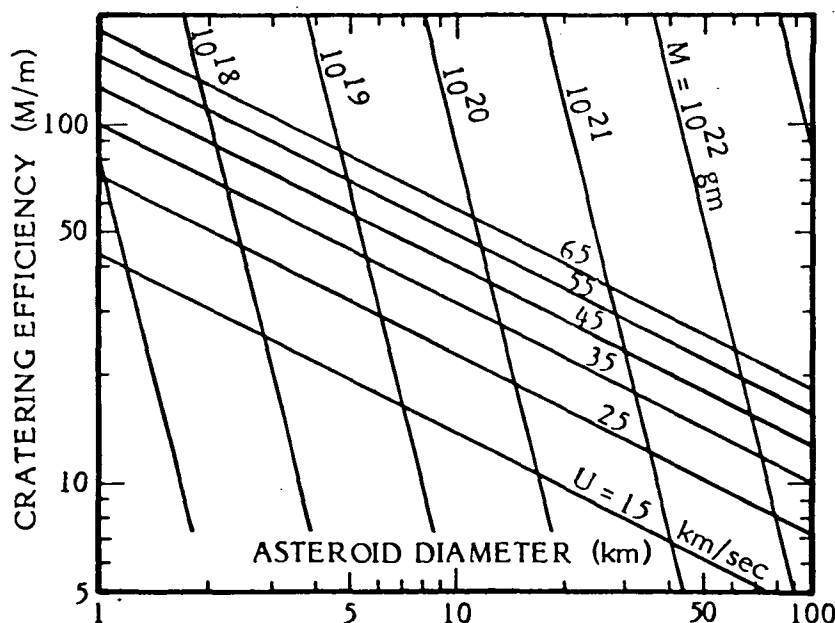
The common practice of using the TEAPOT ESS nuclear event to scale large body impact phenomena vastly overestimates crater size. Holsapple¹ shows that this nuclear event was buried too deeply and furthermore that no single explosive event is appropriate for all impact conditions. An alternative approach is to use scaling relationships based upon centrifuge impact experiments as was done in a recent analysis of Meteor Crater.² These results indicate that earlier estimates of the energy were too small by as much as a factor of five or more. An independent numerical simulation of Meteor Crater³ supports this conclusion.

Application of the centrifuge results to the large-body impact problem is facilitated by using appropriate dimensionless similarity parameters to provide scaling laws for the regime of interest. From this, a simplified expression for cratering efficiency of terrestrial impact can be written as follows: $M/m = CU/d^{0.5}$, where M is the crater "mass" (volume times density), m is the asteroid mass, U is the impact velocity in km/sec and d is the asteroid diameter in km. For typical geology of interest, the material constant C is equal to 900. For granular or porous dry soils that constant can be as small as 600 and for saturated or dense geology it can be as large as 1200. This variation is primarily due to the effect of air void fraction upon coupling mechanisms. For the 10-km diameter asteroid at 25 km/sec suggested by Alvarez⁴, the cratering efficiency would be 22.5 ± 7.5 depending upon specifics of the geology. The mass ratio ejected upwards is somewhat less since as much as one-half of the crater cavity is due to the downward flow that produces the uplift in the lip region.⁵

This analysis indicates that the upward-ejected mass ratio should be on the order of 10 instead of 60 as assumed by Alvarez. In which case, his calculation based upon the total mass of a world-wide clay layer results in an asteroid diameter of 13.6 km.

The figure is a plot of cratering efficiency versus asteroid diameter for various impact velocities of interest. Lines of constant crater "mass" are shown also.

- 1) Holsapple K.A. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, p. 2379-2401.
- 2) Schmidt R.M. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, p. 2099-2128.
- 3) Roddy D.H. et al. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, p. 2275-2308
- 4) Alvarez L.W. et al. (1980) *Science* 208, p. 1095-1108.
- 5) Croft S.K. (1980) *Proc. Lunar Planet. Sci. Conf. 11th*, p.2347-2378.



EXTINCTION OF THE DINOSAURS. T.J.M. Schopf, Dept. Geophysical Sciences, Univ. of Chicago, Chicago, IL 60637

The first step in any scientific program is to determine the problem to be solved. The often popular view that thousands of species of dinosaurs went extinct in the space of a year or two, world wide, is not true. The firm evidence is that during the last 2 to 3 m.y. of the latest Cretaceous (= the latest part of the Maastrichtian stage), a total of about 16 species (representing 15 genera and 10 families) which had been living along the margins of a large seaway (which once extended from the Gulf of Mexico to the Arctic Circle) died off as the seaway dried up. Elsewhere in the world, local populations of dinosaurs had evidently died out before the latest Cretaceous both in Mongolia and in southern Europe. Possibly a species persisted in northern Europe into the latest Cretaceous. Seen in this light, the extinction of the dinosaurs is a perfectly understandable phenomenon - indeed no different than the fate of millions and millions of previous species. The reason why the extinction of the dinosaurs has attracted so much non-scientific attention by scientists and others is that (1) it doesn't cost anyone anything, (2) it sounds impressive, (3) it's basically a rather unimportant scientific problem, though a rather important popular problem, and (4) hard paleontological data are difficult to obtain.

IMPACT CRATERING IN AN ATMOSPHERE ¹P. H. Schultz and ²D. E. Gault

¹Lunar and Planetary Institute, Houston, Texas 77058, ²Murphys Center for Planetology, Murphys, California 95247

Experiments performed with the NASA-Ames Vertical Gun reveal the dynamics of impact cratering in an atmospheric environment. Although at small sizes, well-established scaling relations in fluid dynamics permit reasonable--or at least informative--extrapolation to large size impacts. Theoretical considerations and preliminary experiments (1) indicated that ejecta dynamics are controlled by three variables: crater size (ejecta velocity), ejecta size, and atmospheric density. On-going experiments are revealing new information on the dynamics of ejecta/atmosphere interactions, the influence of controlling variables, the role of impact/atmosphere coupling, and atmospheric effects on energy-scaling relations.

At laboratory scales the median size of ejecta must be less than a critical size before aerodynamic drag significantly affects trajectories (1), and scaling relations dictate the use of pumice dust (median size $\sim 50\mu$). Changing the atmospheric density for a given target material is equivalent to changing either the crater size (ejecta velocity) or ejecta size. Impacts into pumice dust were performed at atmospheric pressures from 1.5 mm (air) to 720 mm (argon) with impact velocities from 100 m/s to 6.4 km/s. At very low relative density ($\rho/\rho_{STP} < 0.07$) crater growth matched those in near-vacuum conditions. At intermediate densities ($0.07 < \rho/\rho_{STP} < 0.3$), the early-time ejecta plume was unmodified but the late-time ejecta curtain developed vortices that modify ejecta emplacement. These vortices appeared at all impact velocities and reflect the response of the atmosphere to the outward moving ejecta curtain. Although at high atmospheric densities ($\rho/\rho_{STP} > 0.5$) the high-velocity, early time ejecta also formed a conical ejecta plume, modification occurred earlier and evolved into a highly turbulent ground-hugging ejecta cloud. The general fall-out component of ejecta was small ($< 5\%$ of ejecta); most of the ejecta was entrapped in the turbulent near-rim ejecta cloud. Experiments with mixtures of particle (ejecta) sizes in the target revealed a two component plume reflecting the relative effects of air drag. Nevertheless near-rim ejecta deposits exhibited extensive mixing of both particle sizes due to the turbulent mode of emplacement. High-velocity projectile swarms were also used in various atmospheric densities. Cratering efficiency is dramatically reduced for impactors with low-bulk density, simulating bodies broken by aerodynamic or gravitational stresses as proposed by Melosh (2). Such impacts result in increased suspended material, increased turbulence, and increased fractions of ejected sintered material.

These experiments should assist in understanding large-body impact phenomena on the Earth. Early-time high-velocity ejecta can escape the impact region through: ballistic shadowing, trajectories in a decreasing atmospheric density, and turbulent vortices. The amount of escaping ejecta depends on the size of the crater relative to the atmospheric scale height. Although the impactor generates a shock wave and ionized wake, these are early-time phenomena that are quickly engulfed by crater growth. The outward-moving ejecta curtain initiates upward air flow in front of the curtain that breaks into vortices suspending the decelerated ejecta fraction. Escaping large-size ejecta may be decelerated to terminal velocity upon re-entry, but the large terminal velocities preclude long-term suspension. Conditions favoring small-size ejecta and long-term ejecta suspension include impact into unconsolidated marine sediments; impact into a deep ocean where dynamic stresses effectively disperse ejected water droplets; or impact by swarms of bodies. The last impact style also may favor increased traces of projectile material in the ejecta. Martian impact craters appear to provide uneroded analogs for aerodynamic effects.

(1.) P. Schultz and D. Gault (1979) *J. Geophys. Res.* 84, 7669-7687. (2.) H. J. Melosh (1981) *Proc. Multi-Ring Impact Conf.* (in press).

EVIDENCE OF OCEANIC IMPACT OF LARGE METEORITES
R.J.Seymour, Scripps Inst. of Oceanography, La Jolla, CA 92093

Assuming a constant ratio of land to ocean areas, 70 percent of terrestrial meteorite impacts have occurred in the oceans. With a 100 million year average age for the present ocean basins, many oceanic impacts by very large meteorites are likely. Because of obvious observational difficulties and sediment ponding, no oceanic craters have been discovered. By a conservative set of scaling laws established from comparisons to both terrestrial and oceanic nuclear explosions, it can be shown that a meteorite of energy 0.3×10^{20} joules will produce a wave train with a 3 minute period and a height of 12 meters measured at a distance of 1500 km from the impact point. This is at least three orders of magnitude more energetic than a tsunami produced by a large submarine earthquake (1). This wave train, impacting the 1:40 slope of a shield type volcanic island, would run up to elevations of as much as 250 m above sea level (1) and would deposit rubble of marine origin to the limits of its uprush. If the impacted island were formed entirely by volcanic processes, marine sediments at great elevations above any previous sea level could be considered anomalous. This type of indirect evidence of oceanic impact occurs frequently in the geological records of the Hawaiian Islands. On the island of Lanai, Stearns (2) found marine conglomerate composed of sand, pebbles, boulders, coralline algae, coral fragments and marine gastropods all of recent origin at elevations up to 350 m above present sea level. These deposits occurred over a broad reach and were as thick as 50 m in one small valley. Blocks of limestone were found at elevations of 190 m. The laterite soil, which is as thick as 15 meters on higher elevations, was stripped away to an elevation of about 350 m all around the island. Stearns (3) found a large field of rounded boulders up to 2 m in diameter at an elevation of 60 m on Kahoolawe I. with no apparent source by conventional terrestrial processes. Stearns (4) also found gravel terraces at elevations up to 330 m in the Waipio region of the island of Hawaii where the steep and narrow valley could be expected to greatly amplify wave runup effects. The Hawaiian chain is believed to have continuously subsided, with increase in elevation caused only by volcanism. This implies that observed elevations of anomalous marine material are in all cases less than those at the time it was deposited. Arguments are presented to show that these examples, and several others, are compatible with the distributions anticipated from a very large wave. Further, it is shown that, in terms of the minimum wave energy required to produce these artifacts, the waves are orders larger than those expected from terrestrial causes. Discussions are presented on the types of locations where similar evidence might be found and a scheme for testing the hypothesis in Hawaii is proposed.

1. Van Dorn, W.G. (1965) *Advances in Hydrosience*, v.2.
2. Stearns, H.T. (1938) *Geol. Soc. of Amer. Bull.*:49, pp615-628.
3. Stearns, H.T. (1946) *Hawaii Div. of Hydrology Bull.*:5.
4. Stearns, H.T. (1935) *Geol. Soc. of Amer. Bull.*:46, pp1927-1956.

SYNTHESIS OF STRATIGRAPHICAL, MICROPALAEONTOLOGICAL AND GEOCHEMICAL
EVIDENCE FROM THE K - T BOUNDARY; INDICATION FOR COMETARY IMPACT.

J. Smit

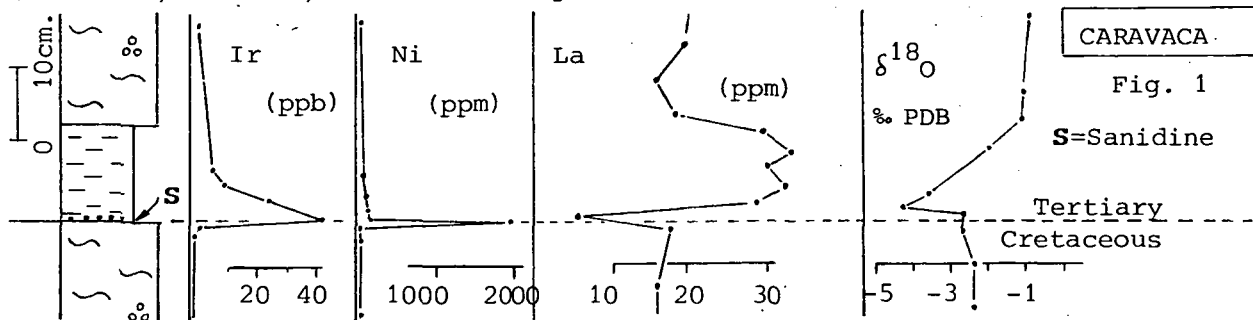
Nieuwe prinsengracht 130, Amsterdam 1018 VZ, Netherlands.

In the most complete pelagic sequences (Caravaca, El Kef), the sedimentation rates are high (6-20 cm/1000 yrs). This makes it possible to sample at time intervals varying from about every 1000 years in bioturbated sediment, to every 50 years when primary bedding is still present, as is the case at the K-T boundary. The foraminiferal mass-extinctions take place within a few mm of sediment, in less than 50 years, and are unannounced in uppermost Cretaceous rocks. (by increasing deviations of micro-paleontological and geochemical variables from mean values for instance). Following the extinctions, biogenic carbonate supply came almost to a stop for about 5000 years. Mainly detrital clay is then deposited, forming the so-called K-T Boundary Clay. Only the basal mm of the Clay contain the anomalously high Ir, Os, Cr, Co, Ni and low REE values (Fig.1) and associated sanidine spherules.⁽¹⁾ This is expected in view of a greatly enhanced supply of extraterrestrial material at the K-T boundary. It is noteworthy that in none of the sections a sediment type, a turbidite for instance, has been deposited indicating a major disturbance of ocean and coastal waters. High values of Ir in higher levels of the boundary clay must be considered reworked. The presence of very low REE values in the basal lamina suggests a high meteoritic contribution. On top of the boundary clay an instable, "pioneering" fauna repopulated the pelagic realm quickly (within a few thousand years). Different planktonic species successively dominate each other in the first 15.000 yrs of the Paleocene.

Our main interpretations of the data from these complete sections are as follows ; A) The extremely short, unannounced mass-extinctions, associated with the mentioned elemental anomalies suggest a catastrophic impact of (an) extraterrestrial body(ies) at the end of the Cretaceous. B) The worldwide distribution of Ir, the absence of a crater, the absence of a turbidite at the K-T boundary, the large meteoritic contribution (30%) in the boundary clay and the warming of ocean surface waters indicate that the projectile(s) entered the atmosphere, but have burnt up for a large part, producing a multitude of 'super' Tunguska events. C) Sanidine spherules in the 'fall-out' lamina and perhaps the high concentrations of 'un-meteoritic' elements like As and Se, associated with the Ir anomaly, may point to cometary material, the more so as K₂O rich spherules have been found at the Tunguska event⁽²⁾

(1) Smit, J. 1981, PhD thesis (unpublished)

(2) Glass, B. 1969, Science 164, p547



HAWAII AS A CONSEQUENCE OF AN IMPACT; PRECIPITATION DRIVEN MAGMA CONVECTION. H. J. Smith and R. Smoluchowski, Dept. of Astronomy, Univ. of Texas, Austin, TX 78712

Alvarez et al. (1) suggested that certain terrestrial isotopic ratios and biological observations may be explained by assuming that an asteroid about 10 km diameter hit the Earth some 65 million years ago. Whipple (2) indicated that Iceland is a likely site of this impact.

We note first that, apart from isotopic and biological consequences, such an impact would lead to gravitational, thermal and volcanic anomalies, and that the Hawaiian hot spot is a plausible site for this or a similar ancient impact. Hawaii shows heat flow and free air positive gravitational anomalies. Interestingly, the rates of motion of the Pacific plate and the length of the Hawaiian and Emperor ridges lead to an epoch for this impact of 60 to 70 million years ago, close to that suggested by Alvarez et al.

An incident asteroidal body would deeply puncture the thin oceanic lithosphere, and the hole would fill by liquid layers from below. Under suitable chemical and dimensional conditions a long-lasting anomaly including a local flexural stress concentration could be formed by Stokes drift of inclusions or later by molecular diffusion. Thus, for example, a portion of the incident body inevitably becomes an implant of denser and probably lower melting materials, the gravitational settling of which would continuously liberate heat in the upper mantle in excess of that in the surrounding material, thus sustaining the convection cell.

Secondly we point out that an important source of additional energy for convection in the upper mantle-asthenosphere may be the heats of solidification of various components of the magma which are playing here a role analogous to the heat of condensation in the cumulus cloud convection in the atmosphere. The solidifying components of the magma heat the liquid and aid its rise. Assuming that the upward velocity of the rising plume of mantle material is of the order of tens of cm/year, and ignoring all heat losses caused by conduction and by entrainment of the colder non-plume material by turbulence at the plume's boundary, one obtains from the solidification process alone a local heat flux of 10^{-4} to 10^{-5} cal cm⁻²sec⁻¹ which is a factor of 10 or so higher than the average heat flux of the Earth.

Supported by NASA grants 44-012-152 and NSG 7505 Sup. 2.

1. Alvarez, L. W., Alvarez, W., Asaro, F., and Michel, H. V., Science, 208, 1095 (1980).
2. Whipple, F. L., Center for Astrophysics preprint No. 1384 (1980).

EXTINCTION OR SURVIVAL AND DIVERSIFICATION: PATTERNS OF SELECTIVITY DURING PALEOZOIC CRISES; Helen Tappan, University of California Los Angeles, Los Angeles, California 90024.

Gradual diversification and replacement of earlier biotas characterize much of the earth's history. Interspersed with the steady and continuous changes in the terrestrial biota were shorter periods characterized by a major reduction in diversity, when sweeping extinctions were not accompanied by approximately simultaneous replacements. Disruptions of preexisting ecosystems followed the selective extinctions, especially when the latter affected productivity and food chains. Each of the major biotic crises, in the Late Cambrian, Late Devonian, Permian and Cretaceous, selectively eliminated particular groups of organisms, these organisms differing as a result of the interactions of the then existing biota with the contemporaneous physical environment, but also reflecting the nature of the selective pressures.

Cambrian extinctions (60 percent of the invertebrate families) affected mostly the then dominant trilobites, but replacement was rapid, as the total family diversity more than doubled during the Ordovician. Devonian extinctions affected 90 percent of the preservable phytoplankton and almost 50 percent of the invertebrate families (especially the suspension-feeding corals, bryozoans, brachiopods, and pelmatozoans, in contrast to survivors among the detritus feeders or macrophagous herbivores), as well as 90 percent of the fish families (mostly the agnathids, and the arthrodire and antiarch placoderms).

The Permian crisis was similar in affecting the passive suspension feeders (about 75 percent each of the coral, bryozoan, and brachiopod families, as well as 97 percent of the species, and 66 percent of the genera of smaller foraminifers, in addition to 100 percent of the fusulines).

In contrast to these Paleozoic crises that almost exclusively resulted in the extinctions of benthic invertebrates and probable bottom-feeding vertebrates, the Cretaceous crisis affected only 30 percent of the benthic invertebrate families, resulted in much greater changes in the plankton and nekton (up to 100 percent of some groups of phytoplankton, planktonic foraminifers, ammonites and belemnites), and eliminated many of the large marine vertebrates (fish and reptilian predators).

Proposed causes of extinction (whether catastrophic and of short duration or due to longer-term climatic fluctuations, changes in continental positions or oceanic extent) must be compatible with the known selectivity of extinctions and the nature of the survivors at these major times of biotic change. Evidence must also be found for a causal relationship rather than only a coincidental occurrence of the catastrophic event and the biotic crisis.

TERMINAL CRETACEOUS PLANKTON EXTINCTIONS: A CRITICAL ASSESSMENT

Hans R. Thierstein, Scripps Institution of Oceanography,
La Jolla, CA 92093

Enormous accumulation of new data and growth of knowledge about the late Phanerozoic history of the earth is occurring through the recovery and study of deep-sea sediments. These records are unique in many ways: They contain microscopic fossils by the thousands and they can be sampled at closely spaced intervals. They are becoming available from around the globe, and their sedimentology and their physical properties are routinely determined.

There is general agreement among specialists, based on the results of high resolution stratigraphy in these pelagic sequences, that the mass extinctions of oceanic plankton at the Cretaceous-Tertiary boundary are real and of unmatched suddenness and severity by any late Phanerozoic standard. Evolution and biogeographic studies of late Cretaceous calcareous phytoplankton remains indicate that oceanic surface environments were ecologically stable through the past few million years prior to the mass extinction event. The few surviving taxa are numerically insignificant in the late Cretaceous and tend to occur sporadically in near-shore and high-latitude paleoenvironments. Catastrophic environmental change in oceanic surface waters is clearly indicated.

Available evidence shows that deep-water benthic foraminifera crossed the Cretaceous-Tertiary boundary unaffected. Somewhat tenuous diversity data on other fossil groups suggest that extinctions were very severe among swimming and floating invertebrates and vertebrates, severe among bottom-dwelling marine invertebrates, and least severe among terrestrial and freshwater organisms.

Any causal catastrophe scenario should be consistent with these observed patterns of environmental selectivity of extinctions. Analogies with environmental tolerances (light, temperature, salinity, toxicants) of living descendants of plankton and other groups may provide answers to the following questions.

Are large body impact scenarios consistent with the observed patterns of environmental selectivity of extinctions? How much light would have to be screened out for how long to seriously impair survival of extant calcareous phytoplankton assemblages? Could any combination of stresses involving light, heat and toxicants account for the observed patterns?

Given the observed severity of plankton extinctions and the known importance of extant plankton as transporting agents of small particles to the ocean floor, could the anomalous chemistry of C/T-boundary clays be a consequence of the mass extinctions, rather than their cause? Necessary tests for these questions also appear to require estimates of accumulation rate changes of sedimentary and chemical components, rather than changes in concentrations. Additional research on the present geochemical cycles of trace and noble elements is clearly needed.

LARGE BODY IMPACTS: EVOLUTION OF THE DUST CLOUD AND ITS EFFECTS ON THE ATMOSPHERE; Owen B. Toon and J. B. Pollack, NASA Ames Research Center, Moffett Field, CA 94035, R. P. Turco, R and D Associates, Marina del Rey, CA 90291, C. P. McKay, University of Colorado, Boulder, CO 80309, M. Liu, Informatics, Inc., Palo Alto, CA 94303.

We have simulated the evolution of an optically thick dust cloud in the Earth's atmosphere, and have also calculated the effects such a dust cloud would have both on the amount of visible light reaching the surface and on temperature at the Earth's surface. The dust cloud simulations utilize a sophisticated 1-d model of aerosol physics. We find that large quantities of dust only remain in the atmosphere for periods on the order of 3 to 6 months. This duration is fixed by the physical processes of coagulation, which causes micron sized particles to quickly form, and sedimentation which swiftly removes the micron sized particles from the atmosphere. The duration of the event is nearly independent of the initial altitude, initial particle size, initial mass, atmospheric vertical diffusive mixing rate, or rainout rate. The duration depends weakly upon the particle density and the probability that colliding particles stick together to form a larger particle. The duration is also limited by the rate at which the debris spreads from the initial impact site. The dust must be uniformly spread over a large fraction of the Earth within a few weeks or the duration of the event will be less than two months. If the Earth encountered a cloud of debris composed of small particles rather than a single solid body the duration of the event would be greater, the problem of distributing the material over a large area of the Earth would be lessened, the absence of any obvious impact crater would be explained, and the high concentration of iridium relative to crustal material could be more easily understood. We used a doubling code to calculate the visible radiative transfer in these dust clouds. For an event with a four month duration the Earth's surface would receive essentially no sunlight for 50 days, the equivalent of full moonlight at 90 days and the equivalent of the sunlight on a very cloudy day at 4 months. Infrared calculations are currently being conducted to determine the impact of the dust on the atmospheric thermal structure and the Earth's surface temperature. These climate calculations and their biological implications will be discussed.

THE TUNGUSKA METEOR: EFFECTS ON STRATOSPHERIC OZONE, ULTRAVIOLET RADIATION, AND CLIMATE. R. P. Turco, R & D Associates, Marina del Rey, CA 90291. O. B. Toon, C. Park and R. C. Whitten, NASA Ames Research Center, Moffett Field, CA 94035. P. Noerdlinger, Michigan State University, East Lansing, MI 48824.

On the morning of June 30, 1908, the Tunguska meteor collided with Earth, devastating nearly 2000 square kilometers of ancient Siberian forest. The powerful air waves and ground tremors generated by the explosion were detected over distances of several thousand kilometers. Yet, no impact craters, and very little meteoric material, were found at the fall site (1). Astrophysicists explain these circumstances in terms of the flight and disintegration in the atmosphere of a small comet or comet fragment composed of ice intermingled with dust (2).

We have investigated the effects of the Tunguska meteor on the upper atmosphere of Earth. Our analysis is based on the results of detailed aerodynamic calculations for the event as constrained by the physical record (3). The major effects involve the dust and water vapor ablated from the cometary body, and the nitrogen oxides (NO_x) generated in the air heated by the meteor. The water and dust probably created noctilucent (mesospheric) cloud displays manifested by 'glowing,' undulating skies, which were reported during the 'light-nights' following the event. By our estimates, the meteoric NO_x was deposited in such prodigious quantities that the stratospheric ozone layer would have been severely depleted in the aftermath of the fall. Evidence for large ozone reductions was sought in the solar spectral data archived by the Smithsonian Astrophysical Observatory (APO) from 1908 to 1912. Statistical analysis of the weak ozone Chappuis band absorption at 0.6 microns revealed a significant ozone recovery trend of $30 \pm 15\%$ between 1908 and 1911. Detailed photochemical model simulations of the aftereffects of the fall predicted maximum ozone depletions of 35-45%. On this basis, a comprehensive physical/chemical picture of the Tunguska event can be drawn which is consistent with the ozone record as well as the barometric and seismic records. Because the complex theory of ozone- NO_x interactions has never been satisfactorily tested under highly-disturbed conditions, as might prevail after a large-scale nuclear war, the Tunguska phenomenon may provide valuable insights into the fidelity of existing photochemical models of the terrestrial ozone balance.

The implications of large meteor-induced photochemical disturbances are manifold. A reduction in stratospheric ozone can lead to an increase in the dose of harmful ultraviolet radiation reaching the ground over the entire planet. Light-sensitive organisms could be damaged as a result. Interrelated alterations in atmospheric ozone, NO_x and dust levels cause changes in heating and cooling patterns that could produce a noticeable climatic shift. Indeed, temperature records indicate that the Northern Hemisphere cooled significantly ($\sim 0.3^\circ \text{C}$) relative to the Southern Hemisphere in the Tunguska epoch, although volcanic activity during this period also contributed to the cooling. Finally, extrapolation of the Tunguska event to much larger encounters suggests that intense showers of cometary fragments could annihilate the ultraviolet ozone shield, perturb the climate, and thereby catastrophically alter the course of evolution on Earth.

1. Krinov, E. L. (1966) Giant Meteorites, Pergamon Press, Oxford, 125-375.
2. Whipple, F.J.W. (1930) Roy. Meteor. Soc. J., 56, 287-304.
3. Park, C. (1978) Acta Astronautica, 5, 523-542.

AN IDEA FOR THE USE OF $^{187}\text{Os}/^{186}\text{Os}$ IN HIGH IRIIDIUM LAYERS IN SEDIMENTARY STRATA AS A CLUE TO DETERMINING COSMIC VERSUS TERRESTRIAL ORIGIN OF SUCH LAYERS. Karl K. Turekian, Dept. of Geology and Geophysics, Yale University, P.O. Box 6666, New Haven, CT 06511.

Allegre and Luck (1) have shown that virtually all classes of meteorites and the mantle source for terrestrial ultramafics have a present-day $^{187}\text{Re}/^{186}\text{Os}$ ratio of about 3.2. ^{187}Re is radioactive ($\lambda=1.6\times 10^{-11}\text{y}^{-1}$) and decays by β^- emission to ^{187}Os . The present-day $^{187}\text{Os}/^{186}\text{Os}$ ratio for unfractionated meteoritic and bulk terrestrial mantle material is 1.03.

Crustal formation processes concentrate Re relative to Os in both granitic and basaltic rocks to yield $^{187}\text{Re}/^{186}\text{Os}$ ratios of 500 to 1000. If the average age of the continental crust is about two billion years, a $^{187}\text{Re}/^{186}\text{Os}$ ratio of about 500 in the crust would yield a present-day $^{187}\text{Os}/^{186}\text{Os}$ ratio of about 17, considerably larger than any mantle or meteorite value. Sedimentary deposits containing osmium derived exclusively from average continental crust, would carry this crustal osmium isotopic imprint. This provides a way of distinguishing between elevated osmium concentrations in sedimentary strata (associated with high iridium concentrations because of geochemical coherence) of terrestrial and meteoritic origin.

The Berkeley group (L. Alvarez, W. Alvarez and F. Asaro), the Paris group (C. Allegre and J.-M. Luck) and the Yale group (K.K. Turekian) are together using this idea to investigate the Cretaceous "iridium" anomalies. If results for one such analysis are available at the time of the meeting they will be presented. The method has the potential of being useful through the Phanerozoic and possibly somewhat earlier in time.

(1) Allegre, C. and Luck, J.-M. (1980) Earth Planet. Sci. Letters, **48**, p. 148-154.

EFFECTS OF COMETARY IMPACTS ON ATMOSPHERIC MASS AND COMPOSITION

G. Hampton Watkins and John S. Lewis^{*}
Department of Earth and Planetary Sciences
Massachusetts Institute of Technology
Cambridge, Massachusetts 02139

A preliminary analysis of atmospheric mass budgets of the terrestrial planets has been conducted. Impacts on the order of 10^{26} , 10^{28} and 10^{31} ergs will initiate removal of atmosphere from Mars, Earth and Venus, respectively. Nearly complete removal of atmosphere above the tangent plane at the point of impact occurs at roughly 10^4 times these energies. The most efficient removal of atmosphere occurs at energies less than an order of magnitude greater than the energies at which atmospheric loss is initiated, and very near the energy at which one-half of the comet mass is retained and one-half lost. The greatest retention of cometary mass occurs within a factor of a few less than the energy required to remove atmosphere down to the tangent plane, i.e. for the largest explosions.

Work is progressing on the convolution of these results with cometary mass flux rates through the inner solar system, and on the assessment of the contribution of cometary volatiles to the terrestrial planet inventories.

^{*}Present address: Department of Planetary Sciences
University of Arizona
Tucson, Arizona 85721

STRATOSPHERIC INJECTION OF OCEAN WATER BY PELAGIC ASTEROIDAL
IMPACTS R.C.Weeks, Lunar and Planetary Laboratory, Univ. of Arizona, Tucson,
AZ 85721

Since the oceans comprise some 3/4 of the Earth's surface, asteroidal impact statistics based upon astroblemes should be multiplied by four to account for ocean impacts, making "hydroblemes" statistically more significant than astroblemes. Pelagic impacts are possibly much more complex than those occurring on land, since the target matter is composed of relatively thin layers of water, sediments, and basalt overlying the lithosphere. Although the detailed hydrodynamics of such impacts are poorly understood, model experiments, at lower velocity than expected for asteroids, suggest the development of a large central peak of ejecta as well as a classical ejecta cone. We give a qualitative assessment of sea water injection into the stratosphere, and the potential modification to natural atmospheric cycles. The water injection may produce significant albedo variations, and the Cl injection from a single impact is large compared to the normal annual atmospheric input, thus constituting a threat to the integrity of the ozone layer. Both the albedo change and the Cl input are possible modifiers of the Earth's biospheric steady state.

TERRESTRIAL IMPACT RATES FOR LONG AND SHORT-PERIOD COMETS. Paul R. Weissman, Jet Propulsion Laboratory, Pasadena, CA 91109

Terrestrial impact rates are calculated for long and short-period comets crossing the earth's orbit. For a long-period comet on a randomly oriented orbit the mean impact probability is 2.2×10^{-9} per perihelion passage and the mean impact velocity is 51.8 km/s. However, the most probable impact energy corresponds to a velocity of 56.6 km/s. Using Everhart's (1967) estimate of ~ 16 long-period comets per AU of perihelion distance per year with $H_{10} < 11.0$ gives a total impact probability of 3.5×10^{-8} or a mean frequency of one impact per 2.8×10^7 yrs. Estimates of nucleus masses for comets indicates that all these comets plus those down to $H_{10} \approx 13.4$ would produce craters of diameter 10 km or greater. This corresponds to a cratering rate of $0.3 \times 10^{-15} \text{ km}^{-2} \text{ yr}^{-1}$ significantly less than that estimated for asteroids (Shoemaker, 1977) or deduced from terrestrial astroblemes (Dence, 1972).

Monte Carlo simulations of the dynamical evolution of long-period comets in the Oort cloud (Weissman, 1981) were used to study changes in the cometary flux over the history of the solar system. If the comets originated among the outer planets with subsequent ejection to the Oort cloud, then the flux of comets returning from the cloud was initially about 100-200 times its current value. If comets originated at greater heliocentric distances then the increase to the flux during the early solar system history was somewhat less. Since the populations of short-period comets and earth-crossing asteroids are both probably derived directly or indirectly from long-period comets, the changes in impact rates for these objects would be expected to parallel that for long-period comets.

Twenty short-period comets are known whose orbits cross the earth's, though seven of these are considered "lost". Another 23 comets are in Amor-type orbits which closely approach the earth and are occasionally perturbed to perihelia within the earth's orbit. Taken as a representative statistical sample the mean impact probability for the 20 earth-crossers is 6.6×10^{-9} per perihelion passage with mean impact velocity of 37.5 km/s. The cumulative impact probability is $1.63 \times 10^{-8} \text{ yr}^{-1}$ and the most probable impact energy corresponds to a velocity of 28.9 km/s. Estimates of nucleus mass are more difficult for short-period comets but all of the 20 are expected to be capable of producing 10 km craters. Assuming that the observational incompleteness of short-period comets is about the same as that found by Everhart for long-period comets, a factor of 24; or by Wetherill (1976) for Apollo asteroids, a factor of 39; the observed sample implies an earth-crossing population of 500 to 800 short-period comets. This results in a terrestrial cratering rate of 0.8 to $1.3 \times 10^{-15} \text{ km}^{-2} \text{ yr}^{-1}$, still somewhat less than that estimated for earth-crossing asteroids or derived from the observed density of terrestrial astroblemes. However, these estimates should be regarded as lower limits because of fainter, unobserved short-period comets which would also contribute to the impacting flux for 10 km craters.

This work was supported by the NASA Planetary Geochemistry and Geophysics Program.

References:

- Dence, M. R. 1972. in 24th Internat. Geol. Cong. Sect. 15, 77-89.
- Everhart, E., 1967. Astron. J. 72, 1002-1011.
- Shoemaker, E. M., 1977. in Impact and Explosion Cratering, Pergamon Press, pp. 617-628.
- Weissman, P. R., 1981. in Comets, Univ. Arizona Press, in press.
- Wetherill, G. W., 1976. Geochim. Cosmochim. Acta 40, 1297-1317.

THE NATURE OF LARGE IMPACTING PROJECTILES

G.W. Wetherill, Dept. of Terrestrial Magnetism, Carnegie Inst. of Washington

There are about 30 known objects of asteroidal appearance in Earth-crossing orbits. By use of completeness-of-search arguments as well as other methods, it is estimated that at the present time there are altogether about 500 objects of this kind in Earth-crossing orbits (Apollo-Aten objects). There are probably two or three times as many in Earth approaching orbits, with $1.0 < \text{perihelion} < 1.3 \text{ A.U.}$ (Amor objects). The distinction between these two populations is not fundamental. As a result of planetary perturbations Apollos become Amors and vice versa on time scales as short as $\sim 10^4$ years. The stochastic impact rate of these bodies with the Earth can be calculated rather accurately, with the result that it may be expected that for the 1 km objects several impacts should be expected every million years and five kilometer diameter objects should impact about once in 20 m.y. at velocities averaging $\sim 25 \text{ km/sec}$. The largest Earth-crossers known at present have diameters of 5 to 10 km, and the largest Amor with a reasonable probability of evolving into an Earth-crosser is 20 km in diameter (433 Eros).

Both the Apollo-Aten and Amor populations are transient, their lifetimes with respect to loss by planetary collisions or ejection from the solar system is short compared with the 4.5 b.y. age of the solar system. A typical Apollo spends 10 to 100 m.y. in Earth-crossing orbit. The observed nearly constant lunar cratering record therefore requires that these transient populations be steady-state populations, losses being supplied by input from one or more sources. This has the consequence that at various times in the past the largest Earth-crosser was probably larger than 5 km, although the cratering record argues that Eros-size objects are about as large as Earth-crossers have been during the last 3 b.y.

Mechanisms are known that transfer a small fraction of the $\sim 10^6$ Apollo-size bodies in the main asteroid belt into Earth-crossing orbit. These involve resonances with the periods and the precession rates of the orbits of the planets, particularly Jupiter, as well as close encounters with Jupiter and Mars. In addition there is evidence from meteor observations, Apollo orbits, as well as from periodic comet Encke (aphelion 4.1 A.U., inside Jupiter's orbit) that some, perhaps most, of the Apollos are not derived from the asteroid belt, but represent the devolatilized residues of once active short period comets. Altogether, an injection rate of about 15 Apollo/m.y. are required to maintain the observed steady-state populations.

It is also likely that small active comets, particularly retrograde comets newly arrived from the Oort cloud, make a significant contribution to the impact rate on Earth. The estimate is very uncertain, because of our poor knowledge of comet diameters and their size distribution. The contribution from active comets could be as high as 40%, or as low as 5%.

HEAVENLY BODY INDEX*

Asteroids

Apollo 43
 Apollo/Amor 43
 Eros 62

Comet Encke 62

Earth 19, 37, 39,
 46, 56, 60

Aouelloul Crater 43
 Araguainha, Brazil 31
 Australia 15, 47
 Brent Crater 43
 Canadian Shield 24
 Clearwater East Crater 43
 Clearwater West Crater 46
 DSDP site 149 2
 Goias, Brazil 31
 Gow Lake 43
 Gulf of St. Lawrence 17
 Haughton Crater 46
 Hawaiian Islands 20,
 51
 Janisjarvi Crater 16
 Kahoolawe Island 51
 Lanai Island 51
 Lappajarvi Crater 43
 Manicouagan Crater 16,
 46
 Maranhao, Brazil 31
 Mato Grosso, Brazil 31
 Nanking, China 2
 Nicholson Lake 43
 Northeastern North America
 24
 Parana Basin, Brazil 31
 Popigai Crater 16, 46
 Riachao ring, Brazil 31
 Ries Crater 43, 46
 Rochechouart Crater,
 France 26, 27, 43
 Saaksjarvi Crater 43
 Serra de Cangalha,
 Brazil 31
 Slate Islands Crater 4
 Sterns Klint 5
 Strangways Crater 43
 Sudbury Crater 16

Earth(CONTINUED)

Superior Province 24
 Tin Bider Crater,
 Algeria 32
 Tunguska site,
 Siberia 22, 52, 57
 Vredefort Crater 16
 Wanapitei Crater 43

Jupiter 62
 Eros 62

Mars 20, 46, 50, 62

Moon 24, 46
 Copernicus 34
 Mare Srenetatis 6

*Pagination refers to the first page of an article in which a heavenly body is cited.

SUBJECT INDEX*

64

A

Accretion 25
Aerosols 14
Airshock 22
Ammonoids 5, 23
Amor objects 62
Angiosperm 19
Anomalies 2
Apollo objects 20, 62
Aquilapollenites 19
Asteroidal impact 53
Asteroids 1, 13, 20, 33, 39, 43, 47, 62
Aten objects 62
Atmosphere 13, 22, 59
Atmospheric dust 56

B

Basin rings 46
Basins 6
Bathymetry 10
Belemnoids 5, 23
Benthic foraminifera 55
Biogeography 47
Biomere 44
Biosphere 60
Bivalves 5, 23
Blastwave 22
Bolides 39
Brachiopods 35
Brazil craters 31
 composition 26
 stratigraphy 27
 suevite-like 27
 thickness 27
Brecciation 4
Brunhes/Matuyama reversal 15

C

Cambrian 44, 54
Carbon-isotopes 45
Cavity morphology 27
Central peaks 13
Chemosynthesis 20
Climate 13, 19, 56
Coccolithophorids 5
Cometary impact 41, 52
Comets 1, 41, 47, 57, 59, 62
 long-period 61
 short-period 61

Complex structures 16
Cooling 6
Corals 35
Cratering 12, 21
 efficiency 48
 rate 16, 61
 terrestrial 16
Craters 34, 37, 46
 exhumed 31
 floor limit 27
 impact 10, 21, 43, 48
 scaling 21, 48
 simple 16
 verification 31
 volume 48
Crenulation 32
Cretaceous 5, 8, 11, 19, 23, 36, 49, 54, 58
Cretaceous-Tertiary boundary 14, 33, 45, 55, 56

D

Deep-sea sediments 18
Devonian 30, 35, 54
Diachroneity 36
Diachronism 19
Dinoflagellates 5
Dinosaurs 11, 19, 36, 39, 49
Ductile deformation 32
 removal 56
 transport 56
 veil 57

E

Ecosystems 54
Ejecta 1, 34, 39, 50, 60
Energy 6, 12

*Pagination refers to first page of an article in which a subject is cited.

Energy(CONTINUED)

coupling	41	
partitioning	16	
Environmental selectivity		55
Eocene-Oligocene boundary		2
Evolution	12, 52	
Explosions	22	
Extinction	1, 5, 8,	
	11, 14, 15, 20,	
	23, 25, 28, 30,	
	35, 36, 39, 44,	
	47, 49, 52, 54,	
	55, 56	

F

Famennian	35	
Foraminifera		5
Fossils	47	
Frasnian	30, 35	

G

Geochemistry	2, 26, 30	
Geochronology	7	
Geologic evidence	46	
Geological detection		34
Global blackout	38	
Gravitational anomaly		53
Gravity anomaly	24	

H

Heat	6	
Heat flux anomaly		53
flow	12	
Hotspots	36	
Hydroblemes	13	
Hydrodynamics	22	

I

Impact	1, 9, 12,	
	13, 14, 17, 20,	
	25, 28, 30, 37,	
	39, 41, 43, 47,	
	51, 59, 60	
ashes	27	
basins, terrestrial		17
experiments	34	

Impact(CONTINUED)

melts	16, 27, 43	
rates	61	
scars	46	
structure	26, 27,	
	32	
Iridium	2, 11, 36,	
	58	
Iridium/abundance anomaly		42
Iron anomaly	26	

J

Jaramillo geomagnetic event	15	
-----------------------------	----	--

K

Kinetic energy	16	
----------------	----	--

L

Limit of deformation	32	
----------------------	----	--

M

Maastrichtian	49	
Magma convection		53
Magnesium anomaly		26
Magnetics	4	
Major elements		26
Melt composition		26
Mesopause	33	
Meteor impact	41	
Meteorites	35, 43, 51	
impact	24, 56	
Meteoritic component		43
Meteors	41, 57	
Microplankton	23	
Microtektites	15	
Mixing process	26	
Modelling	6	
Models	34	
Multi-ring structure		32
Multi-ringed basins		46

N

Nannoplankton	55	
---------------	----	--

Neutron activation 2
 Noctilucent clouds 33
 Normapolles 19

O

Oceans 9, 37, 51,
 60
 floor 10, 34
 impact 50
 Oort cloud 61
 Osmium-187 58
 Oxygen isotope data 15

P

Paleobiogeography* 28
 Paleoclimates 18
 Paleoecology 28
 Paleoenvironments 30
 Paleomagnetism 7, 11
 Paleontology 7, 11
 Paleoproductivity 45
 Paleozoic 54
 Palynological/K-T boundary 42
 Palynology 11
 Partitioning 6
 Pelagic 13, 52, 55,
 60
 Permian 54
 Permian-Triassic boundary 2
 Photosynthesis 14, 20
 Phytoplankton 38
 calcareous 45
 Planar elements 31
 Plankton 28
 biogeography 55
 evolution 55
 extinctions 55
 Pleistocene 18
 Polarity 7
 Pre-Cambrian 20
 Precipitation 53
 Projectile types 16
 Projectiles 62

R

Radiation 14
 Radiations 28
 Radiolarians 18

Rhenium-187 58
 Ring spacing 46

S

Sanidine 52
 Scaling 13, 21
 Seafloor 34
 Sedimentary target 32
 Sediments 2, 25, 58
 Seismology 4
 Selectivity 54
 Shock indicators 31
 Shock metamorphism 32
 Shock wave 39
 Siderophiles 16, 25
 Slumping 34
 Solidification 53
 Stratigraphic uplift 32
 Stratigraphy 7, 11, 45
 Stratosphere 57, 60
 Stress 6
 Structural geology 32
 Subsidence 6

T

Target composition 26
 Tectonics 6
 Tektites 15
 Tertiary 8, 11, 19
 Thrusting 32
 Topographic rim 46
 Transgression 35
 Transient-cavities 13
 Trilobites 44
 Tsunamis 51
 Tunguska meteor 57
 Turbidity 35

U

Ultraviolet radiation 57

V

Vaporization 9
 Vertebrates 8
 Volcanoes 53
 Volumetric estimates 27

	W
Water	9, 34, 60
Waves	13
Weather	57

A

Ahrens T. J. 1, 39
 Alvarez L. W. 2
 Alvarez W. 2
 Asaro F. 2
 Awramik S. M. 3

B

Bengtson M. E. 4
 Birkelund T. 5
 Borden W. F. 41
 Bratt S. R. 6
 Butler R. F. 7

C

Cannon W. F. 24
 Clemens W. A. 8
 Croft S. K. 9

D

Dietz R. S. 32

E

Eckhoff O. 10

F

Fassett J. E. 11, 42

G

Gaffney E. S. 12
 Ganapathy R. 30
 Gault D. E. 13, 50
 Gerstl S. A. W. 14
 Gilmore J. S. 42
 Glass B. P. 15
 Goetz P. 34
 Grieve R. A. F. 16

H

Hartung J. B. 17
 Hays J. D. 18

He Q. 45
 Head J. W. 6
 Hickey L. J. 19
 Hoagland R. C. 20
 Holsapple K. A. 21
 Houfani M. 32

J

Johnson N. M. 7
 Jones E. M. 22

K

Kauffman E. G. 23
 Klasner J. S. 24
 Knight J. D. 42
 Kyte F. T. 25

L

Lambert P. 26, 27, 32
 Larson S. A. 41
 Lewis J. S. 59
 Lindsay E. H. 7
 Lipps J. H. 28
 Liu M. 56
 Lowenstam H. A. 29

M

McGhee G. R. Jr. 30
 McHone J. F. 31, 32
 McHone J. F. Jr. 31
 McKay C. P. 33, 38, 56
 McKenzie J. 45
 McKinnon W. B. 34
 McLaren D. J. 35
 McLean D. M. 36
 Melosh H. J. 37
 Meyer R. P. 4
 Michel H. V. 2
 Milne D. H. 38

N

Noerdlinger P. 57

0
 O'Keefe J. D. 1, 39
 Olsen E. J. 30
 Olson E. C. 40
 Orphal D. L. 41
 Orth C. J. 42

P
 Palme H. 43
 Palmer A. R. 44
 Park C. 57
 Perch-Nielsen K. 45
 Pike R. J. 46
 Pillmore C. L. 42
 Pollack J. B. 56

R
 Raup D. M. 47
 Roddy D. J. 41

S
 Sandford M. T. 22
 Schmidt R. M. 48
 Schopf T. J. 49
 Schultz P. H. 41, 50
 Schulz K. J. 24
 Seymour R. J. 51
 Smit J. 52
 Smith H. J. 53
 Smoluchowski R. 53
 Solomon S. C. 6
 Sonett C. P. 13

T
 Tappan H. 54
 Thierstein H. R. 55
 Thomas G. E. 33
 Toon O. B. 56, 57
 Tschudy R. H. 42
 Turco R. P. 56, 57
 Turekian K. K. 58

V
 Vogt P. R. 10

W
 Wasson J. T. 25
 Watkins G. H. 59
 Weeks R. C. 60
 Weissman P. R. 61
 Wetherill G. W. 62
 Whitaker R. W. 22
 Whitten R. C. 57
 Z
 Zardecki A. 14

SUPPLEMENT TO

*Check Register
for basic fee*

**PAPERS PRESENTED TO THE CONFERENCE ON
LARGE BODY IMPACTS AND TERRESTRIAL EVOLUTION:
GEOLOGICAL, CLIMATOLOGICAL, AND
BIOLOGICAL IMPLICATIONS**

**OCTOBER 19-22, 1981
SNOWBIRD, UTAH**

Sponsored by:

**Lunar and Planetary Institute
National Academy of Sciences**



UNIVERSITIES SPACE RESEARCH ASSOCIATION
LUNAR AND PLANETARY INSTITUTE
3303 NASA ROAD 1
HOUSTON, TEXAS 77058

SUPPLEMENT TO
PAPERS PRESENTED TO THE CONFERENCE ON LARGE BODY IMPACTS
AND TERRESTRIAL EVOLUTION: GEOLOGICAL, CLIMATOLOGICAL, AND
BIOLOGICAL IMPLICATIONS

October 19-22, 1981
Snowbird, Utah

Sponsored by:

*Lunar and Planetary Institute
National Academy of Sciences*

Compiled by:

*Lunar and Planetary Institute
3303 NASA Road One
Houston, Texas 77058*

LPI CONTRIBUTION NO. 449

TABLE OF CONTENTS

<i>Ejecta facies of the Ries Crater, Germany</i> F. Hörz	1
<i>Terminal Cretaceous event</i> K. J. Hsü, Q. X. He, and J. McKenzie	2
<i>Mass extinctions--Illusions or realities?</i> N. D. Newell	3
<i>A non-catastrophist explanation for the iridium anomaly at the Cretaceous/Tertiary boundary</i> M. R. Rampino	4
<i>Effects of terrestrial mega-impact cratering events</i> D. J. Roddy, P. A. Davis, L. A. Soderblom, K. N. Kreyenhagen, D. L. Orphal, M. Rosenblatt, and S. H. Schuster	5
<i>Internal effects of the impact of average-size meteorites</i> J. Rondot	7
<i>Collision of asteroids and comets with planets and satellites in late geologic time</i> E. M. Shoemaker	8

EJECTA FACIES OF THE RIES CRATER, GERMANY

Friedrich Horz, SN6, NASA Johnson Space Center, Houston, TX 77058

The Ries Crater has a diameter of 26 km, is 15 m.y. old, and is by far the best preserved, "large" terrestrial (≥ 3 km D) crater. It penetrated a sedimentary sequence, 600 m thick, and terminated in crystalline basement. Three distinct facies of ejecta beyond the crater rim may be distinguished: (a) "Bunte Breccia" (BB), (b) "Suevite" and (c) "Moldavite" tektites.

The most voluminous and widespread deposit is BB (~ 200 km³); it is poorly sorted with clasts $\gg 10$ m residing in a fine-grained (< 1 cm) matrix. Suevite volume beyond the crater rim is ~ 5 km³; it is also poorly sorted; maximum clast size is rarely > 1 m; the matrix is rich in clay and fine-grained detritus ($\sim 60\%$ by weight, < 1 mm); it is characterized by crystalline clasts of all shock levels and aerodynamically shaped glass bombs. The Moldavites are typical, holohyaline tektites found in Czechoslovakia and contribute a negligible volume. Measured from the crater center, the maximum radial extent of BB is ~ 3 r, that of suevite ~ 2 r and the moldavites occur at 20-30 r. Considering the extent of erosion and uncertainties in the exact geometry of the excavation cavity, all displaced Ries materials can essentially be accounted for within 3 r; high speed ejecta beyond 3 r appear volumetrically insignificant.

Some observations relevant to the Cretaceous/Tertiary Event (CTE) are:

a. All ejecta deposits beyond the crater rim are poorly sorted in radial and vertical profile; components < 1 mm typically comprise $> 20\%$ by volume. Aerodynamic drag and associated grain size sorting appear inefficient. Aerodynamic sculpturing of the suevite glass bombs, however, argues against complete lack of atmospheric interaction. These observations are compatible with a turbulent, radially expanding atmosphere or impact-generated vapor cloud. Without exception suevite is deposited on top of BB and the contacts are knife-edge sharp; the entire BB was deposited while suevite was still being ejected. Because the lack of aerodynamic sorting is particularly evident in the "late" suevite, atmospheric disturbance must have lasted on the order of minutes.

b. The suevite glasses are derived from the deep-seated crystalline basement, but the moldavite melts most likely are derived from the Tertiary silts and sands forming the Ries' cap rock. Moldavite melts are thus temporally (earlier) and spatially (at the target's surface) different from the bulk of the impact melts; this may apply to all high speed ejecta.

c. Suevite matrices from different localities are chemically similar, a feature akin to the remarkable homogeneity of large terrestrial impact melt sheets as well as suevite melts and moldavites. Thus, if the CTE materials are impact products, they should have a globally identical progenitor.

d. Although "shocked" (by optical criteria) components are almost exclusively confined to suevites, they nevertheless occur in BB also and are even reported from tektites. A concentrated search for shocked mineral detritus may be fruitful in CTE materials, where preservation of such detritus can reasonably be expected.

In summary: No continuous ejecta deposits at radial ranges > 5 r are known for any large terrestrial crater. Suevites, however, are found at a number of craters (e.g., Sudbury, Mien, Lappajarvi, Popigai). At the Ries they indicate significant atmospheric disturbance for relatively long times. The terrestrial cratering record yields only tektites and microtektites as the sole, although crucial, evidence for potentially global ejecta dispersion.

TERMINAL CRETACEOUS EVENT. Kenneth J. Hsü, Q.X. He, J. McKenzie, Swiss Federal Institute of Technology, Zurich, Switzerland.

Lyellian Uniformitarianism has served its usefulness to sweep away superstitions of theologically bent naturalists of the 19th century. However, Lyell's insistence on linear rates and steady states has hindered ready acceptance of earth science theories which invoke catastrophic rates.

The discovery of unusual concentrations of siderophile elements such as iridium, in K-T boundary sediments at relative concentrations similar to those in carbonaceous chondrites provided the first definitive indication of the impact of an extra-terrestrial body (Alvarez et al., 1980; Ganapathy, 1980). The finding of sanidine spherules in the iridium-rich layer suggested that the body was a comet (Smit, 1981). The report of 65 m.y. old craters at Kamensk and at Gusev and of another with 60 ± 5 m.y. age at Karst (Masaylis, 1981) gives hope that they may prove to be the burial sites of the "Smoking Pistols" of the great terminal Cretaceous extinction.

The abrupt decrease of CaCO_3 -content and the carbon-isotope shift of the terminal Cretaceous sediments may be the expressions of the Strangelove Effect (named after the fictitious character who conspired to bring about radical perturbation of the terrestrial steady state). A drastically reduced production of ocean planktons should minimise the difference between the ocean's surface and bottom waters, bringing deep corrosive waters with excess ^{12}C to the photic zone. The magnitude of a 3 ‰ $\delta^{13}\text{C}$ anomaly in sediments deposited less than a thousand years after the impact of event suggests additional excess ^{12}C atoms brought in by the decay of a terrestrial biomass destroyed by mass mortality; and possibly also by additional extraterrestrial light carbon from the more soluble portions of a comet (Hsü, 1980).

Available data do not permit a positive conclusion on the total carbon-isotope budget of the oceans, but data from DSDP Site 524 suggest a build-up of excess C^{12} during the 30,000 years after the impact. Oxygen isotope data are consistent with the prediction of cooling, when impact ejecta reduced the influx of solar radiation, and of a subsequent warming, probably caused by the greenhouse effect of excess CO_2 in the atmosphere released by an ocean of reduced fertility.

Our scenario portrays mass mortality of ocean planktons caused by poisons (cyanides, osmium, ruthenium, arsenic etc.) released to the surface currents of the oceans by a partially disintegrated fallen comet. The stress environment subsequent to impact suppressed the production of calcareous plankton and prevented their recovery, leading to their catastrophic extinction.

Large terrestrial reptiles, such as dinosaurs, as endangered species after the impact event, may have become completely extinct because of their inability to withstand thermal stress. Other groups of organisms suffered more or less, depending on their geographical habitats and upon their resistance to environmental stresses.

MASS EXTINCTIONS — ILLUSIONS OR REALITIES?

Norman D. Newell, *Am. Mus. Nat. Hist.*, New York, N. Y. 10024

Extinction is a continuous process as shown by the fact that almost all fossil taxa are extinct. But when diverse organism assemblages finally disappear at, or near, a single geological horizon, it is a temptation to postulate a catastrophic event. Superficial appearances of mass extinction, however, may be misleading. An indication of decline in diversity may not be sufficient to establish the reality of any revolutionary change.

There are many obvious and some obscure sources of error involved in sampling the fossil record. Precise time-correlations are usually lacking and the raw data on taxon ranges are systematically misleading. The standard method of reporting fossil ranges artificially concentrates last occurrences at stratigraphic boundaries. A similar effect may also result from an unrecognized sedimentary hiatus (paraconformity), which may simulate a mass extinction event.

Many biological revolutions are indeed real, as shown by diverse clues of environmental perturbations on a world scale. Generally, however, they were spread over millions of years and can be considered catastrophic only in the perspective of the final stage in an accelerating downward trend in diversity.

A NON-CATASTROPHIST EXPLANATION FOR THE IRIDIUM ANOMALY AT THE CRETACEOUS/TERTIARY BOUNDARY: M.R. Rampino, NASA, Goddard Institute for Space Studies, New York, N.Y. 10025

The thin boundary clay layer and iridium anomaly in marine limestone sections at the Cretaceous/Tertiary boundary can be explained by; 1) concentration of the insoluble clay and Ir-rich meteorite ablation material during dissolution of CaCO_3 and 2) iridium enrichment in the clay by submarine weathering, trace metal scavenging, and perhaps current winnowing on the sea floor. This view is supported by elevated levels of iridium in manganese nodules and some Pliocene and Pleistocene pelagic sediments.

The K/T boundary zone is commonly marked by a break in the sequence. Hardgrounds and pyritic/phosphatic seams are common in shallow water carbonate and chalk sequences. The Danish "fish clay" sections are classic examples. These anomalous lithologies indicate a period of carbonate dissolution and slow rates of deposition. Pelagic limestone sequences similarly affected might be expected to produce a thin layer of clay containing iron sulfides, phosphates and perhaps manganese, and enriched in insoluble components of the limestone, especially siderophile-rich meteoritic material. This is a good description of the K/T boundary clay.

Chemical differences between the boundary clay and the normal clay component of the limestones can be explained by submarine weathering and leaching processes. A comparison of the mineralogy of the boundary clay with the clay contained in the limestones might serve to test the fallout model. The presence of fish skeletal debris and lack of bioturbation in boundary-clay layers argues against the ejecta-blanket interpretation.

The handful of studies that have analyzed iridium in deep-sea deposits (sediments and Mn-nodules) at places other than the K/T boundary have all found some concentrations that can be considered anomalous in terms of crustal abundances. The question is then what constitutes an iridium anomaly? Although it seems probable that the source of the iridium is extraterrestrial in all these cases, the concentrating processes for the Ir may be sedimentary, chemical, or biological.

The terminal Cretaceous extinctions of calcareous plankton could be a result of a rise in the CCD and the appearance of CaCO_3 undersaturated waters at the ocean surface. However, if the K/T boundary is marked by a widespread dissolution event in the oceans, and a global hiatus, then the simultaneity of the disappearance of numerous taxa in many sections may be an illusion created by a stratigraphic break. The dramatic regression of the sea 65 million years ago, and the climatic and ecologic consequences of that event, seem sufficient to explain the biotic crises among terrestrial- and shallow-water organisms at or near the K/T boundary.

EFFECTS OF TERRESTRIAL MEGA-IMPACT CRATERING EVENTS

D. J. Roddy, P. A. Davis, L. A. Soderblom, (U.S. Geological Survey, Flagstaff, AZ); K. N. Kreyenhagen, D. L. Orphal, M. Rosenblatt, S. H. Schuster, (California Research and Technology, Woodland Hills, CA).

Hypervelocity impact craters have been recognized on all of the terrestrial planets, the Moon, and most of the satellites of Jupiter and Saturn. It has been generally accepted that the majority of these craters, especially the larger ones, were formed several billion years ago. Recent field, laboratory, and theoretical studies, however, have each concluded that the Earth, and presumably the other planets and satellites, have continued to experience a small number of impact events that were large enough to have major effects on the geologic and biologic records [1,2,3,4]. Our understanding of the topical and global effects of such events, however, has been quite limited.

Recently, O'Keefe and Ahrens [5] have completed preliminary studies of certain aspects of large, terrestrial cratering events, such as energy transfer to rock and ocean targets and to the atmosphere. We have also initiated preliminary studies of several aspects of mega-impact events. For example, a projectile 10-km in diameter ($\rho \sim 3 \text{ gm/cm}^3$; $\sim 10^{12}$ metric tons; $\sim 5 \times 10^{30}$ ergs) traveling at 25 km/sec will cause a transient excavation of a 10-km diameter column of air along its trajectory, and will form a massive bow shock wave (~ 2 to 4 kb initial pressure) that expands outward through a region tens of thousands of cubic kilometers in size. Both a strong thermal and an EMP pulse should be generated. Assuming an atmospheric depth of ~ 100 km (scale depth ~ 7 to 10 km), the penetration time for the impacting body would be only ~ 4 seconds for a vertical trajectory, and ~ 5 seconds for one with a 15° angle of impact. If the leading half of the body suffers ablative removal to a depth of only one centimeter (during short atmospheric travel time), then $\sim 10^6$ tons of projectile will be lost; if ablative removal extends to a depth of one meter (longer atmospheric travel time), then $\sim 10^9$ tons will be lost. This is a small fraction of total projectile mass, but the distribution of such ablation "dust" at different altitudes, and its dispersion as a function of projectile trajectories and atmospheric circulation patterns at different altitudes, require further examination to determine the effects on atmospheric albedo and terrestrial heat exchange.

We have estimated the apparent diameter of the crater formed by such an impacting body to be ~ 100 km (apparent diameter, i.e., measured at the original ground level) by using the volume, diameter and profile-scaling information derived from our numerical code calculations for Meteor Crater [6]. We would expect the general crater shape to be approximately flat-floored, with either central uplift or multirings (or both), and to have an apparent crater volume of $\sim 2 \times 10^4 \text{ km}^3$. The length of time to form the crater using different explosion and impact scaling data is estimated to be on the order of 10 to 20 minutes, however it may be longer depending on criteria used to define "end-of-cratering." The percent of mass in the continuous ejecta blanket and within 2 to 3 crater diameters of the impact point is estimated from explosion and impact data to be ~ 80 to 85% of the total excavated volume. The percent of mass of discontinuous ejecta (some forming secondary craters) beyond the continuous blanket is estimated to be ~ 5 to 10% of the excavated volume, and the percent of mass raised to very high altitudes in high-velocity ejecta and "fireball-equivalent" lofted

EFFECTS OF TERRESTRIAL MEGA-IMPACT CRATERING EVENTS

Roddy, D. J., et al.

debris is estimated to be ~ 1% to 10% of the excavated volume. At speeds of 25 km/sec, all of the projectile mass should vaporize. A mixture of high-velocity ejecta of vaporized projectile and target should combine and rise in the "fireball-equivalent" processes.

Assuming a simple flat-floored crater with central uplift, scaling estimates of the maximum depth of total disruption below the uplifted region indicate a transient crater depth of ~ 20 to 40 km and implies crust/mantle interactions [7]. If the impact occurred in an ocean that had an average depth of ~ 3 km, the maximum height of the water wave at initial rim crest is estimated to be ~ 2.5 to 3 km. Structural uplift of the underlying rock would probably raise the total rim-crest height to 5 to 10 km [8]. Some of the water vapor (and CO₂ if projectile was a comet) produced by the impact could be expected to nucleate on the widespread fine debris that was ejected and lofted to different altitudes and a seeding effect would follow. This should produce rain which would tend to remove particulate debris from the lower climate-producing altitudes. We suggested that certain chemical reactions in the atmosphere involving these materials, in addition to certain toxic vapors such as NH₃ and SO₂, could have led to prehistoric acid rain that would have been less than comforting to most life-forms.

As yet, no large crater has been identified that correlates in time with the proposed Cretaceous-Tertiary event, but this is not surprising with ~ 75% of the Earth covered by water (assuming the same land/water distribution 65 million years ago). Considering the uncertainties of the ages of some of the large terrestrial craters, such as Popigay (now dated from end of Cretaceous to ~ 20 million yrs ago), it may be that further field studies may yield an acceptable impact site in terms of time. These problems, as well as a number of other questions regarding mega-impact events and effects, will hopefully be addressed by an increasing number of workers in the near future.

References:

- [1] Alvarez, L. W., Alvarez, W., Asaro, F., and Michel, H. V. (1980) Extraterrestrial cause for the Cretaceous-Tertiary extinction: Science, v. 208, p. 1095-1108.
- [2] Kyte, F. T., Zhou, Z., and Wasson, J. T. (1980) Siderophile-enriched sediments from the Cretaceous-Tertiary boundary: Nature, v. 288, p. 651-656.
- [3] Masaytis, V. L., Mikhaylov, M. V., and Selivanovskaya, T. V. (1975) Popigayskiy Meteoritnyy Krater: Moscow Nauka Press, 124 p.
- [4] Shoemaker, E. M., Williams, J. G., Helin, E. F., and Wolfe, R. F. (1979) Earth-crossing asteroids: orbital classes, collision rates with Earth and origin, in Asteroids, Gehrels, T., ed.: Tucson, University of Arizona Press, p. 253-282.
- [5] O'Keefe, J. D., and Ahrens, T. J. (1981) (abstract) Lunar and Planetary Science XII, p. 785-787.
- [6] Roddy, D. J., Schuster, S. H., Kreyenhagen, K. N., and Orphal, D. L. (1980) Proc. Lunar Sci. Planet. Conf. 11th, p. 2275-2308.
- [7] Roddy, D. J. (1979) Structural deformation at the Flynn Creek impact crater, Tennessee: A preliminary report on deep drilling: Proc. Lunar Sci. Planet. Conf. 10th, p. 2519-2534.
- [8] Roddy, D. J., Ulrich, G. W., Sauer, F. M., and Jones, G. H. S. (1977) Proc. Lunar Sci. Planet. Conf. 8th, p. 3389-3407.

INTERNAL EFFECTS OF THE IMPACT OF AVERAGE-SIZE METEORITES

Jehan Rondot, Geological Surveys, 1620, boul. de l'Entente, Québec, Québec,
G1S 4N6

Most astroblemes (10-100 km diameter) show a rapid readjustment of the original crater tending to reestablish equilibrium and heal the affected surface by doubling the diameter of the crater. Uplift of the center is compensated by annular collapse outside the crater. The medial part does not show great displacement (Rondot, 1970, Can. J. Earth Sci. 7, p. 1195).

On the moon, the transition between these astroblemes and small dish-shaped craters is narrow (Pike, 1977, Proc. Lunar Sci. Conf. 8th, p. 3428).

Observations

Vertical displacements of the crater bottom upwards and of the sides downwards are observed and can be calculated in almost all astroblemes; drill holes in the Sierra Madera (Wilshire, 1972, USGS Prof. Paper, 599H) indicate that such displacements do not affect deep strata. Very thin sedimentary cover resting in place on crystalline basement is preserved in the collapsed part of many astroblemes. This indicates the maximum diameter of the original crater and allows comparison of such astroblemes.

The edges of lunar craters are usually sharp, and on the inside there are benches. Although weakened by erosion, these features are present at Charlevoix.

In crystalline terrain, readjustment occurs by movement of blocks separated by relatively narrow zones of mylonitization (breccia dikes: Rondot, 1969, Meteorites 4, 291). Even the central hill at Charlevoix is a little deformed block. There are faults, but very little folding associated with astroblemes in general.

Proposed explanations

High pressure studies using explosions are instructive about the original crater and the nature of the ejecta. But for impacts, there is a residual pressure after first passage of the shock wave, caused by descent of the meteorite, and this continues until complete transformation of the kinetic energy (Rondot, 1975, Bull. Geol. Inst. Univ., Uppsala, N.S. 6, p. 86).

This downward movement is channeled along spiraloidal surfaces towards the only possible expansion, i.e., the earth's surface at a certain distance from the compressed zone, as had been demonstrated experimentally (Muhs, 1966, in Proc. of the 6th Int'l. Conf. on Soil Mechanics and Foundation Eng., vol. III, pp. 419-421, Univ. of Toronto Press).

The readjustment to reestablish lithostatic equilibrium uses the same surfaces, but in the opposite sense. The friction that reduces the rock to powder gives off heat and water under pressure. This mixture, serving as a lubricant between the blocks, allows a substantial reduction in the yield strength which is theoretically necessary for the readjustment (Melosh, 1977, Impact and Explosion Cratering, p. 1245).

Conclusion

Regardless of appearance, astroblemes have appreciably the same geometry. The prominent central hill in some astroblemes in fact represents less than 1% of the total volume of the central uplift (10% of the vertical movement during uplift). With certain exceptions, the depth of fracturing in the continental crust is insufficient for the mobilization of magma.

In the transformation of the kinetic energy, the relative speed of the meteorite must play a role in the degree of fragmentation of the ejecta and therefore in the quantity of dust distributed in the atmosphere, thus influencing the climate and the biosphere and perhaps also the timing of glacial periods.

COLLISION OF ASTEROIDS AND COMETS WITH PLANETS AND SATELLITES IN LATE GEOLOGIC TIME: Eugene M. Shoemaker, U.S. Geological Survey, Flagstaff, AZ 86001.

The lunar surface carries the best record of impact cratering in the neighborhood of the Earth during the last several billion years. Time control from isotopic age determinations of lunar samples shows that the rate of bombardment decayed approximately exponentially between 3.9 and 3.3 billion years ago. Over the last 3.3 Gy the mean rate of production of craters equal to or larger than 10 km diameter is estimated at $0.6 \pm 0.3 \times 10^{-14} \text{ km}^{-2} \text{ yr}^{-1}$. When corrections are applied for differences in the capture cross-sections of the Earth and Moon, differences in surface gravity and differences in the collapse of 10 km craters, the equivalent rate of cratering on the Earth is estimated at $0.9 \pm 0.5 \times 10^{-14} \text{ km}^{-2} \text{ yr}^{-1}$. This may be compared with a mean terrestrial rate of cratering during the Phanerozoic, down to 10 km crater diameter, of $2.2 \pm 1.1 \times 10^{-14} \text{ km}^{-2} \text{ yr}^{-1}$ obtained by Shoemaker [1] and a rate of $1.4 \pm 0.4 \times 10^{-14} \text{ km}^{-2} \text{ yr}^{-1}$ derived from the work of Grieve and Dence [2]. The estimated present production of terrestrial craters to 10 km diameter by impact of Earth-crossing asteroids, assuming that half the Earth crossers are C-type and half are S-type asteroids, is $\sim 2 \times 10^{-14} \text{ km}^{-2} \text{ yr}^{-1}$ [3].

The icy satellites of Jupiter also carry a record of impact cratering in late geologic time. If the youngest impact basins on Ganymede are assumed to be approximately contemporaneous with the youngest basins on the Moon and the heavy bombardment of Ganymede is assumed to have decayed in the same manner as on the Moon, then all the ray craters on Ganymede were formed in the last ~ 2 Gy. The corresponding rate of crater production to 10 km diameter on Ganymede in late geologic time is similar to the Phanerozoic cratering rate on Earth. Analysis of the flux of solid objects in Jupiter's neighborhood indicates that more than 95 percent of these late impacting bodies are active or extinct comet nuclei [4]. The rate of cratering to 10 km diameter by comet impact on the Earth, moreover, is found to be roughly half the rate due to impact of Earth-crossing asteroids.

The comets which cross the Earth's orbit have predominantly long period (nearly parabolic) orbits, and the mean encounter velocity of these comets with the Earth is much higher than the mean encounter velocity of Earth-crossing asteroids. Therefore, the comet flux is only weakly concentrated by the gravitational field of the Earth. As many as half the 10 km craters on the Moon produced in the last 3.3 Gy may have been formed by comet impact. On Mercury, the present production of 10 km impact craters may be dominated by comet impact, and the total cratering rate is approximately the same as on the Moon. On Mars, on the other hand, the present production of craters is due predominantly to impact of Mars-crossing asteroids.

Energy- and size-frequency distributions of impacting bodies that formed craters in late geologic time on the Earth and Moon can be estimated from the size-frequency distribution of post-mare lunar craters. During the Phanerozoic, bodies as large as 15 km diameter may have struck the Earth with an average frequency of 10^{-8} yr^{-1} .

[1] Shoemaker, E.M. (1977) in *Impact and Explosion Cratering* (Pergamon Press) 617.

[2] Grieve, R.A.F., and Dence, M.R. (1979) *Icarus* 38 230.

[3] Shoemaker, E.M., Williams, J.G., Helin, E.F., and Wolfe, R.F. (1979) in *Asteroids* (Univ. of Arizona Press) 253.

[4] Shoemaker, E.M., and Wolfe, R.F. (in press) in *The Satellites of Jupiter* (Univ. of Arizona Press).